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(54) **ARTICULATED WHEEL ASSEMBLIES AND VEHICLES THEREWITH**

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Related U.S. Application Data

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Publication Classification

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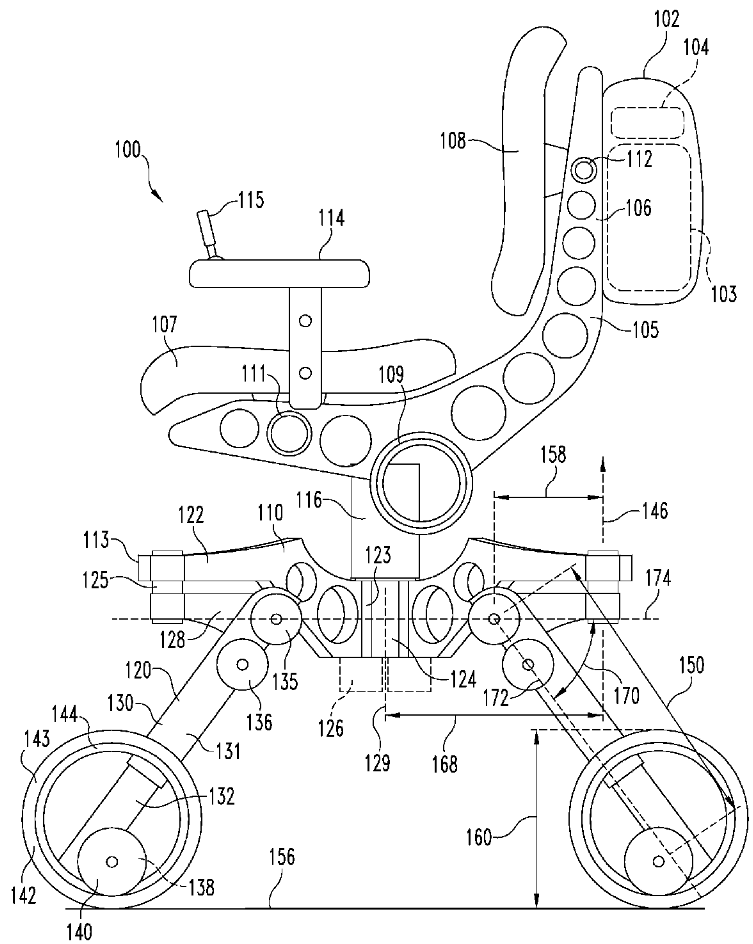
(52) **U.S. Cl.** **280/649**

(57) **ABSTRACT**

The disclosed articulated wheel assemblies and associated vehicles, for example wheelchairs, include articulated wheel assemblies with at least one offset connecting arm rotatably attached at one end to a payload platform, for example a seat, and attached at the other end to a linear actuator, where the linear actuator is further connected to a wheel. Embodiments include a rotary actuator for varying the linear actuator swing angle, a rotary actuator for eccentrically rotating a hubless wheel, a linear actuator motor for varying the length of the linear actuator, and a propulsion motor. Embodiments provide omnidirectional motion, stepping action when presented with obstacles, irregular surface negotiation, tight space maneuvering and other features to provide disabled people increased mobility. Alternate embodiments include a payload platform with a support strut, which is rotatably attached to an offset connecting arm and pivotally mounted to a seat.



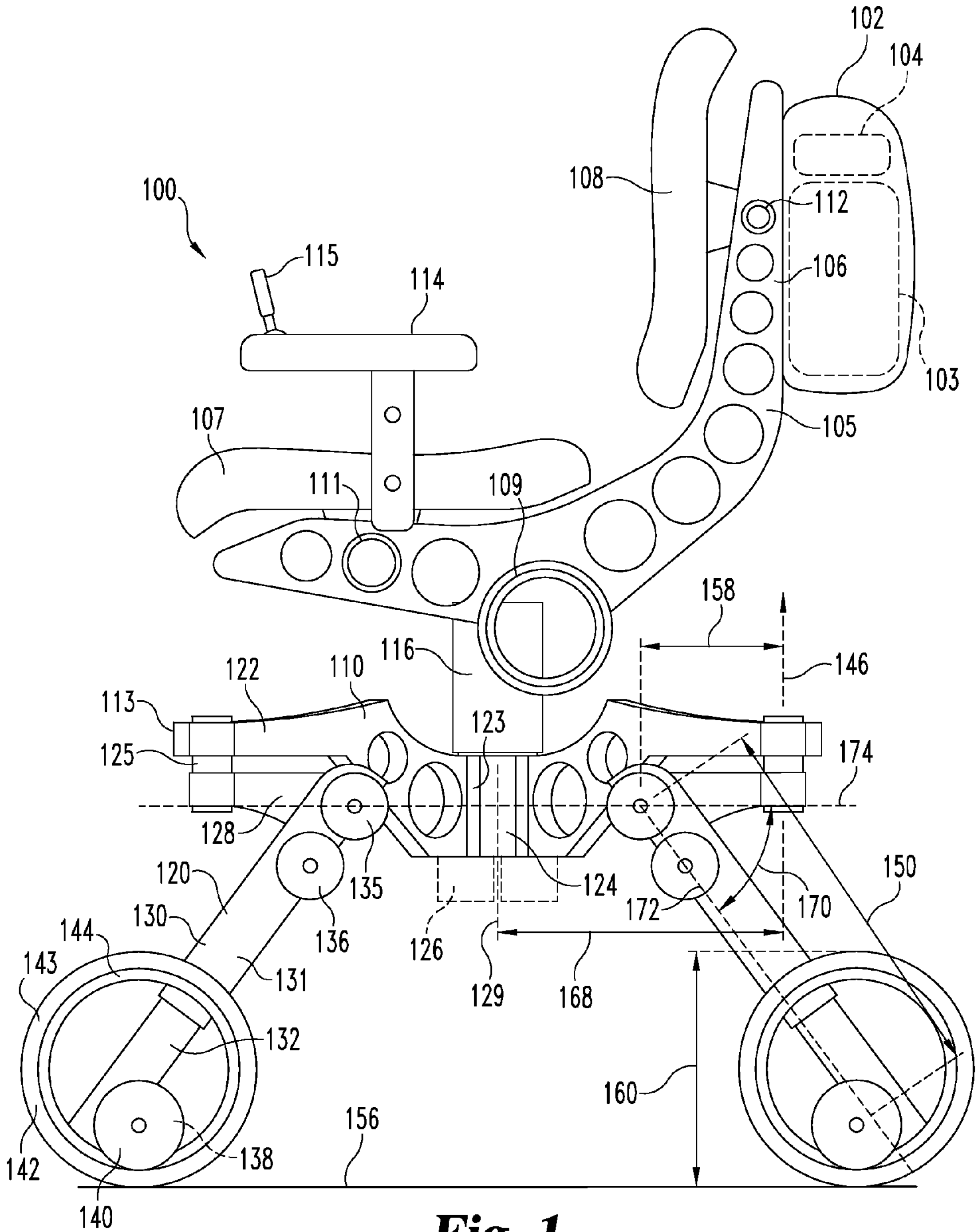


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Fig. 1

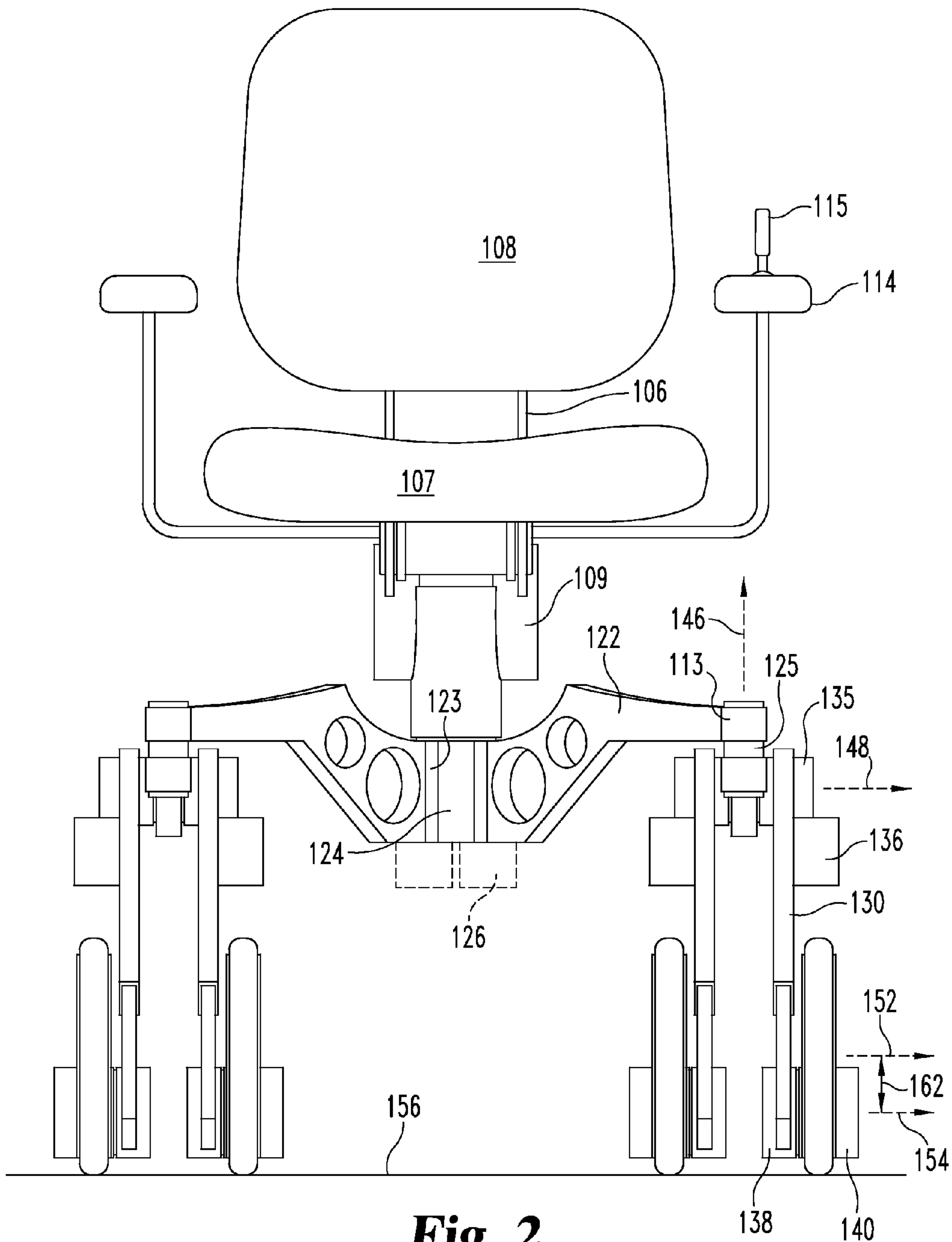
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Fig. 2

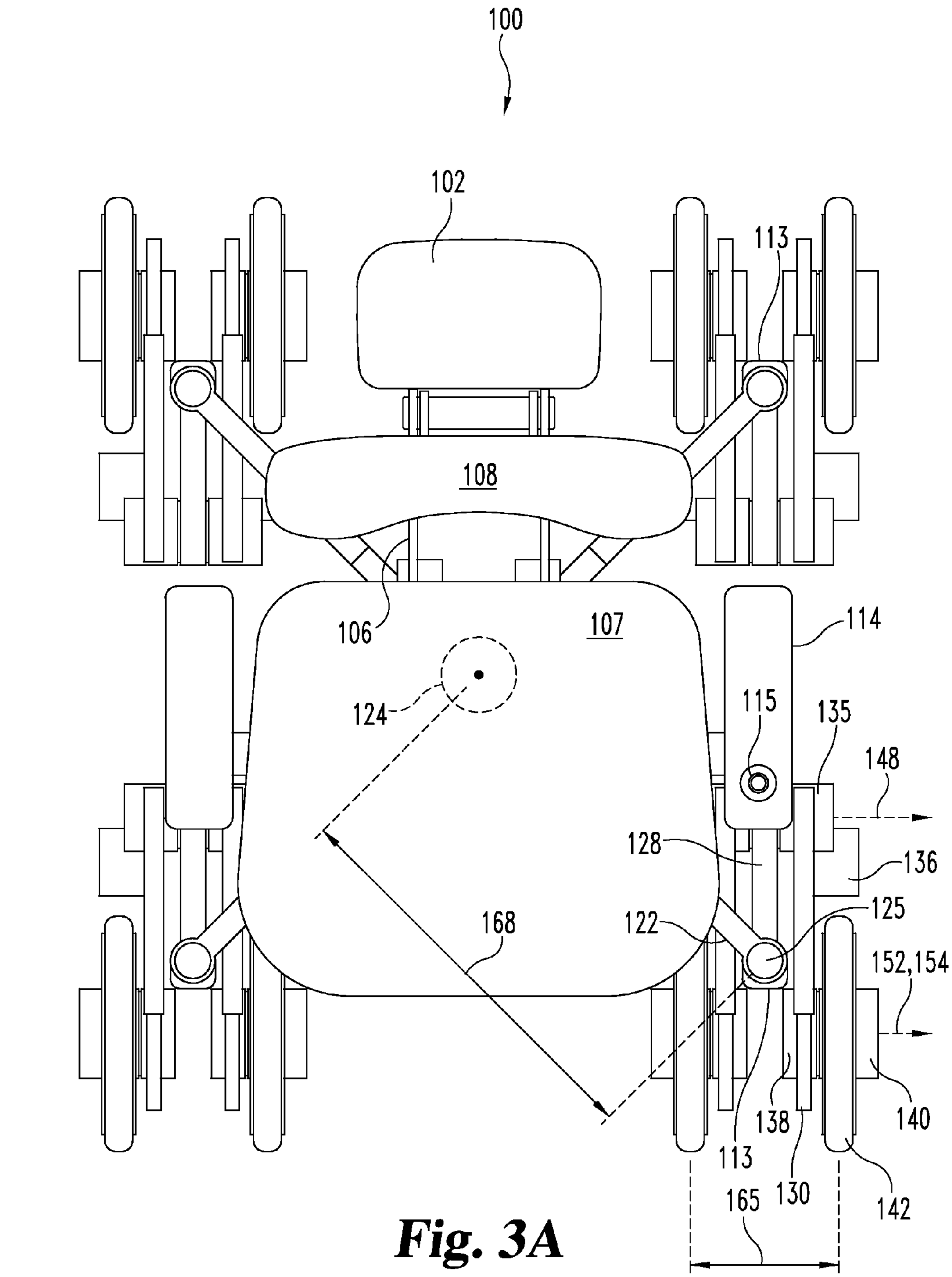
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Fig. 3A

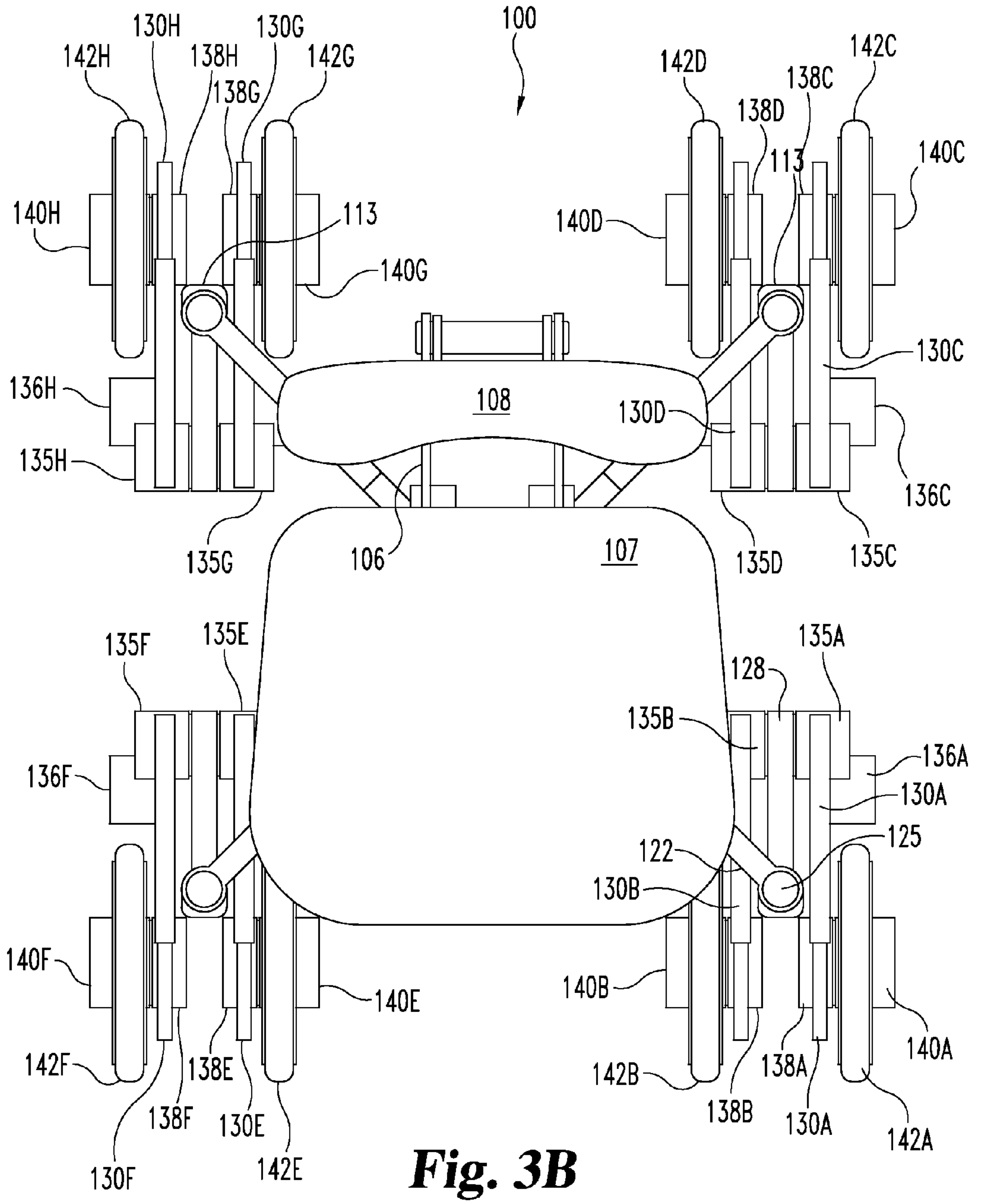
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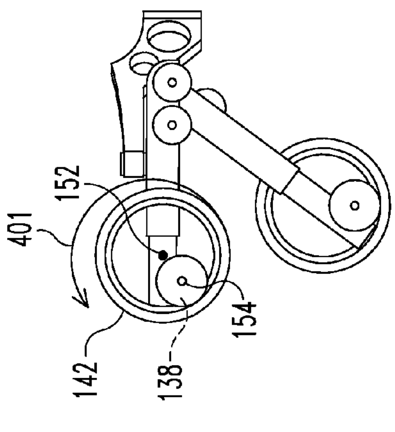
Fig. 3B



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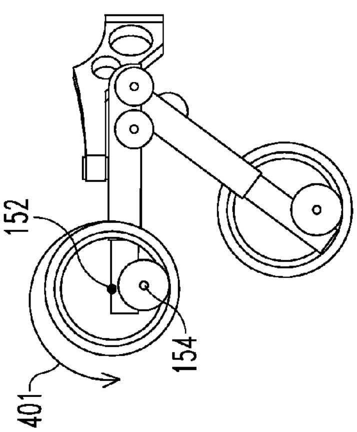

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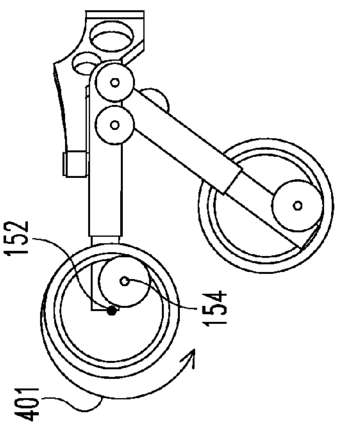

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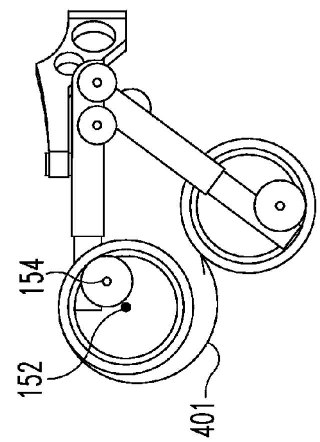

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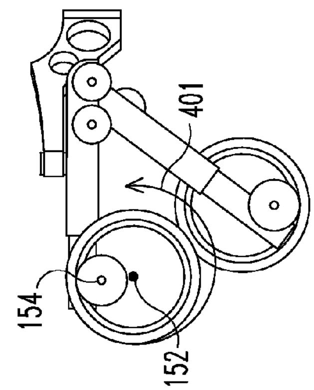

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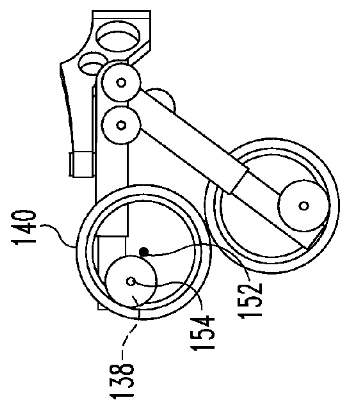

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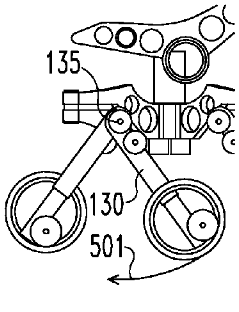

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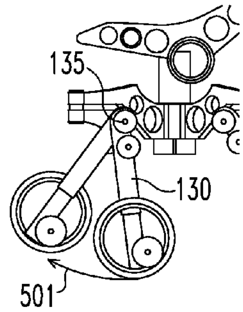

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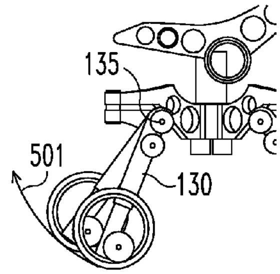

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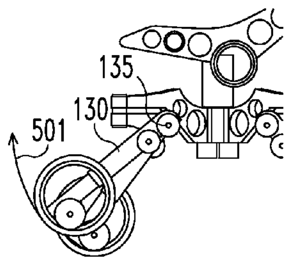

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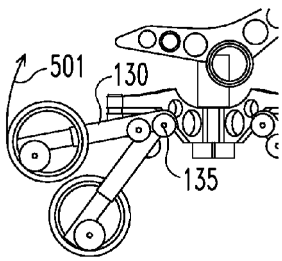

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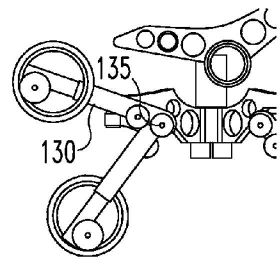

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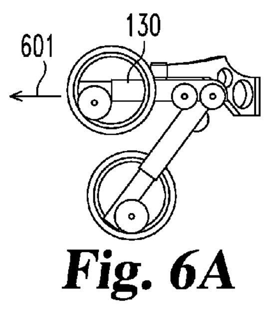

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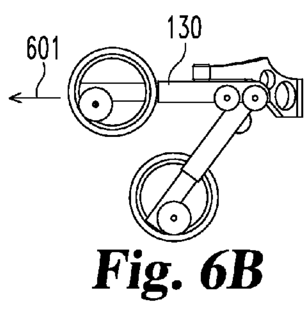

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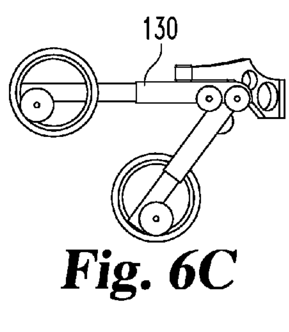

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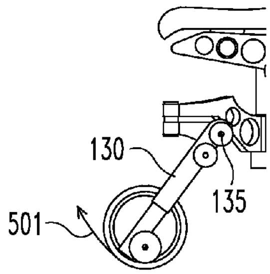

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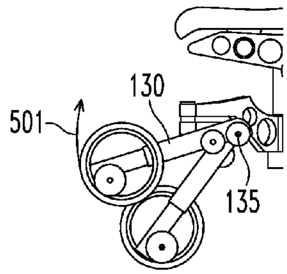

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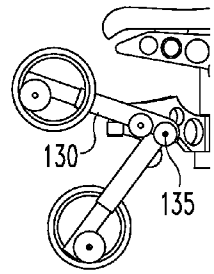

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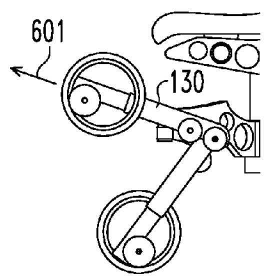

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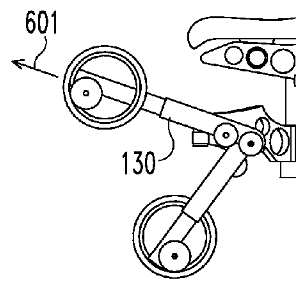

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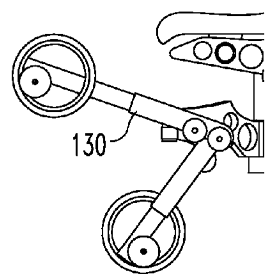

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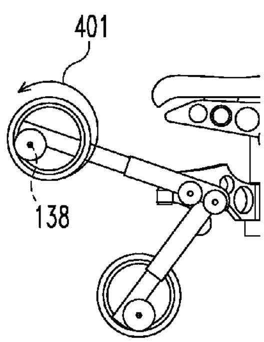

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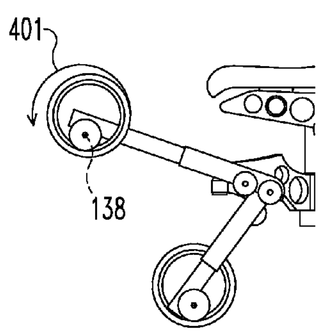

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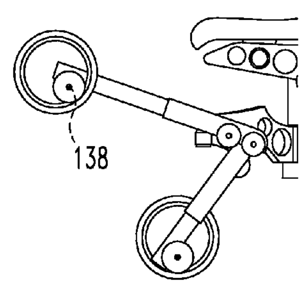

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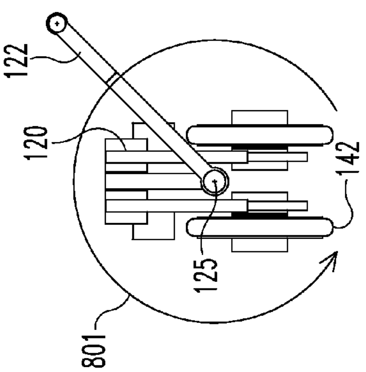

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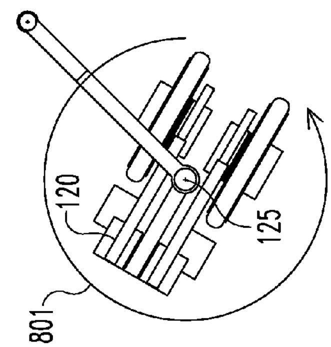

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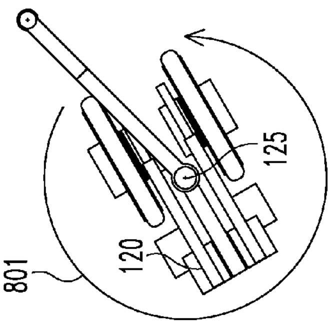

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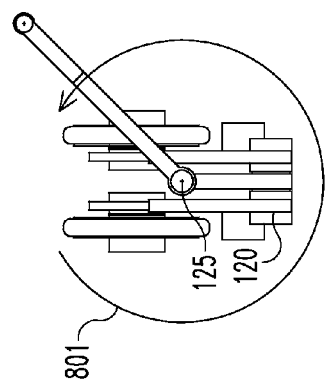

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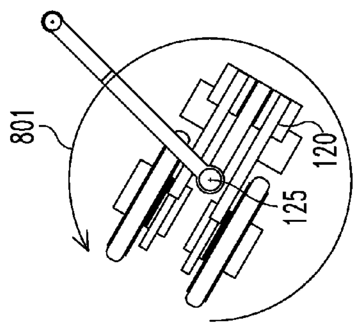

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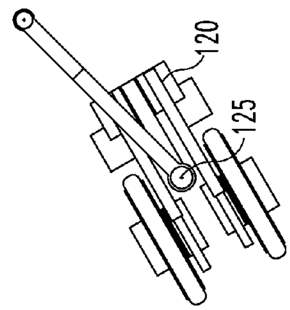

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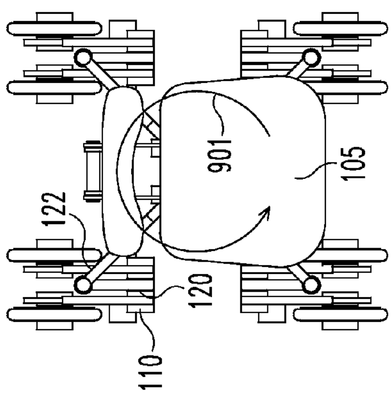

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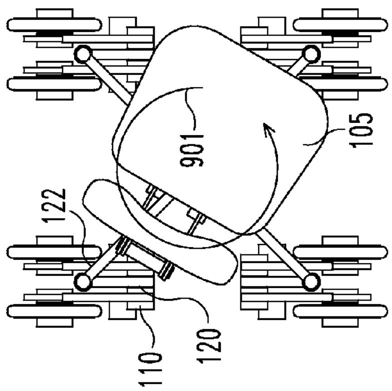

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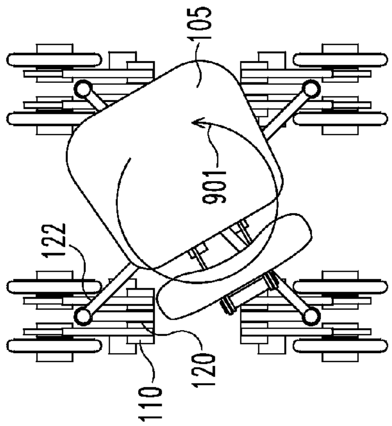

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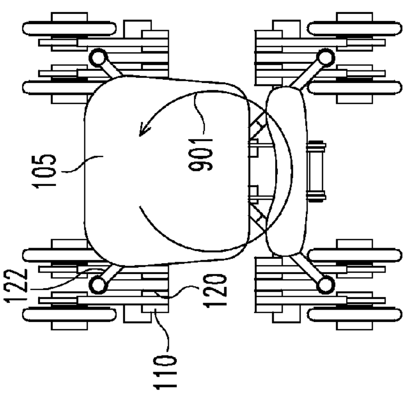

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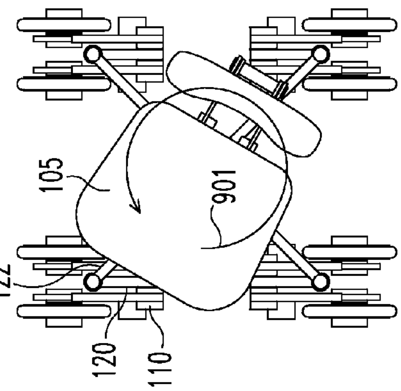

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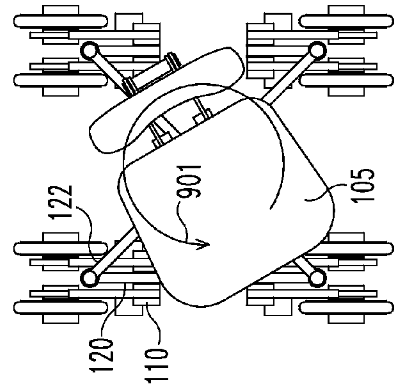

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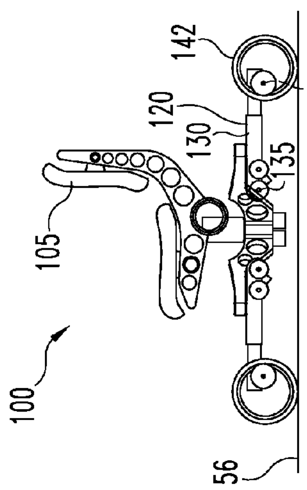

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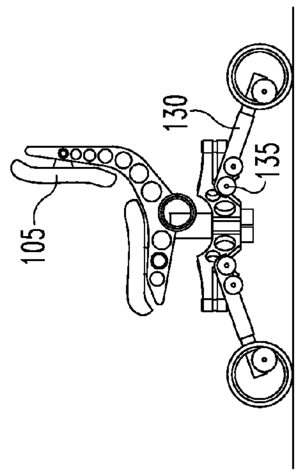

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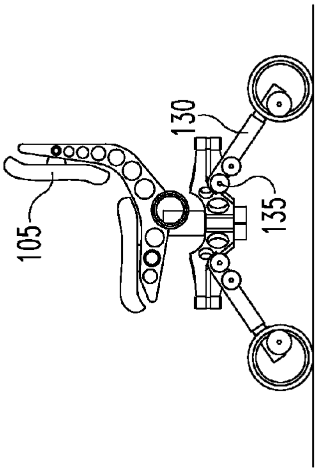

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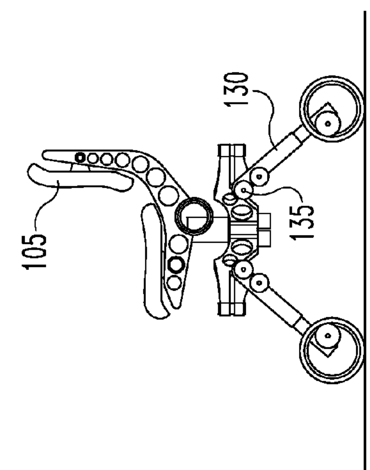

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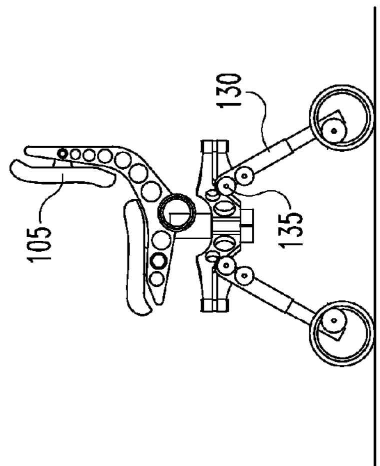

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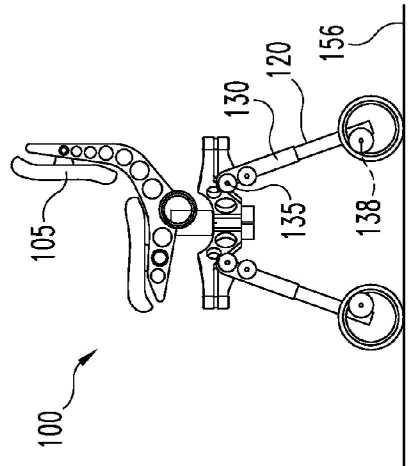

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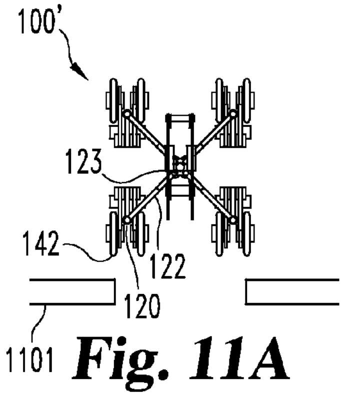
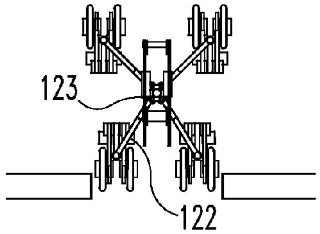


Fig. 11A



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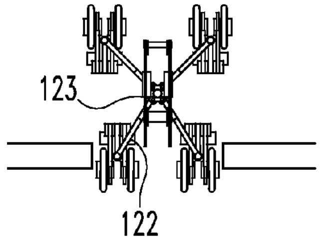

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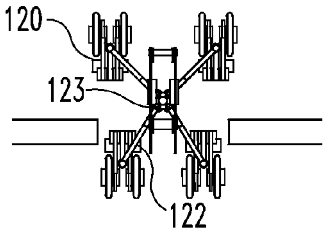

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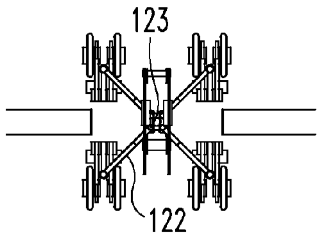

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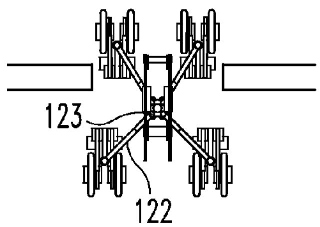

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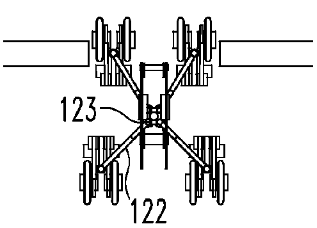

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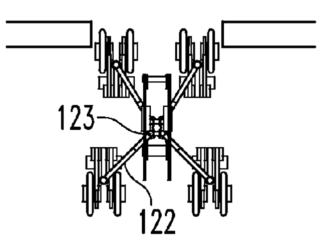

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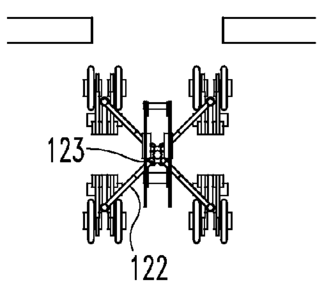

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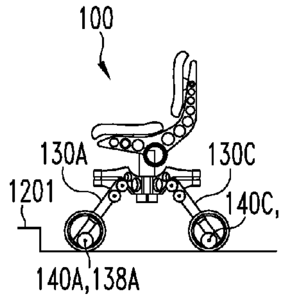

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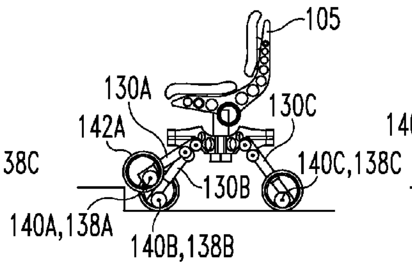

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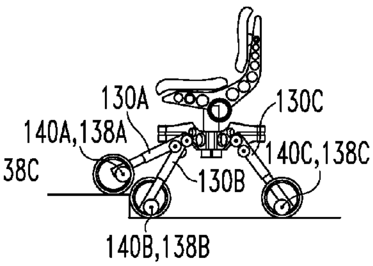

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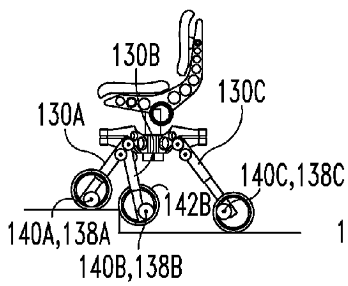

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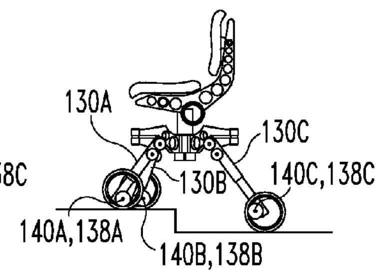

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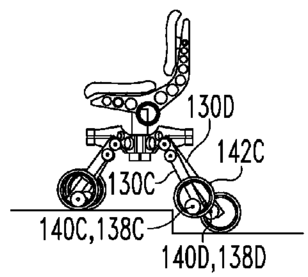

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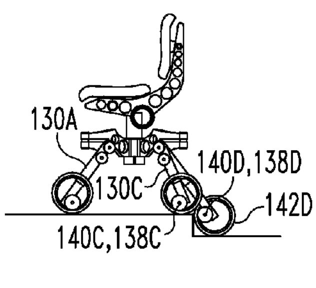

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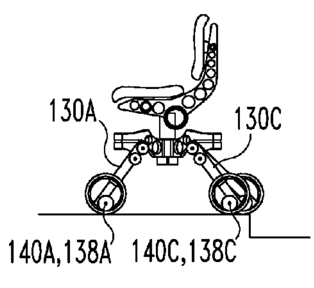

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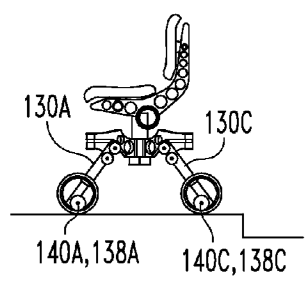


Fig. 12I

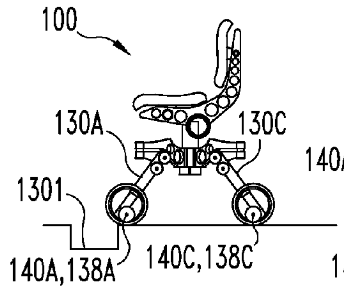


Fig. 13A

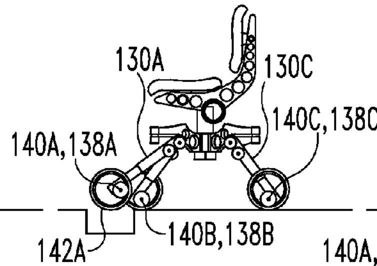


Fig. 13B

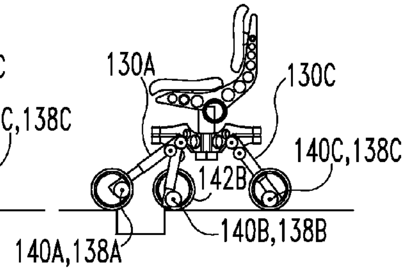


Fig. 13C

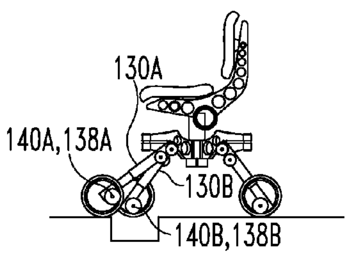


Fig. 13D

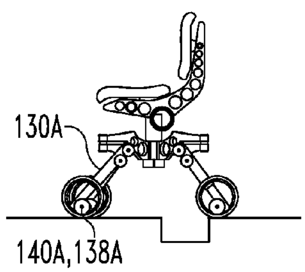


Fig. 13E

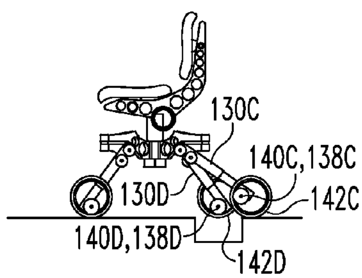


Fig. 13F

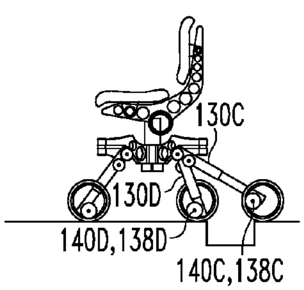


Fig. 13G

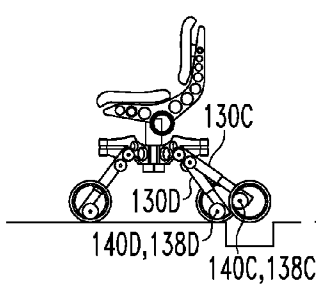


Fig. 13H

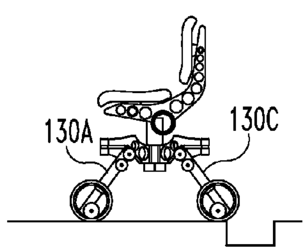


Fig. 13I

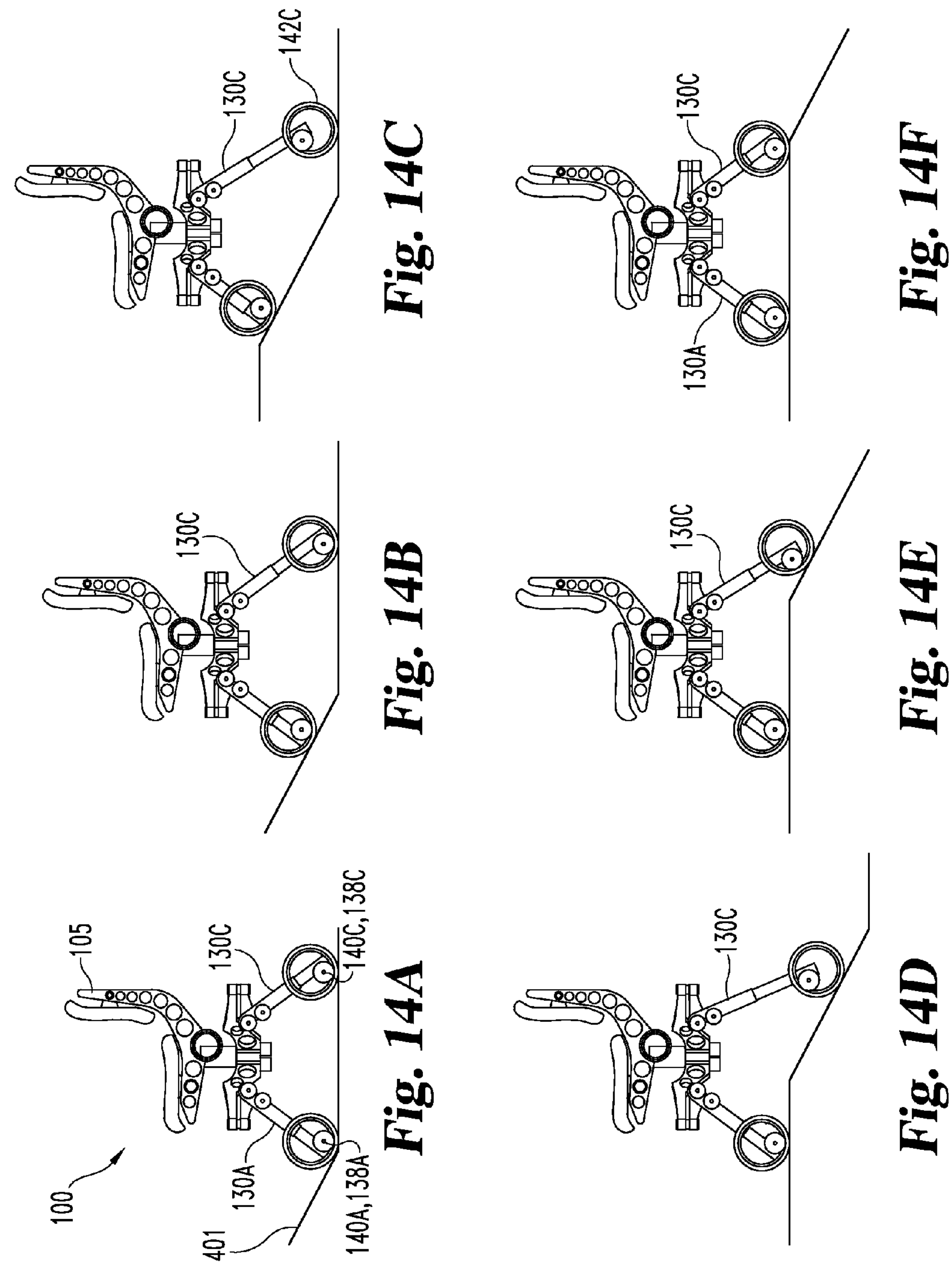


Fig. 14A

Fig. 14B

Fig. 14C

Fig. 14D

Fig. 14E

Fig. 14F

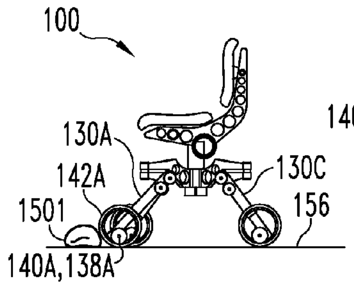
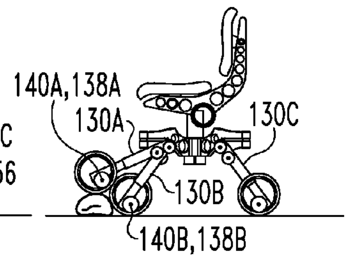


Fig. 15A



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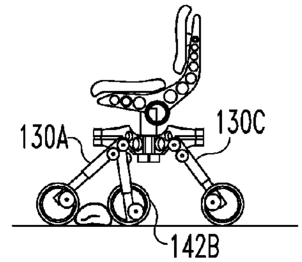


Fig. 15C

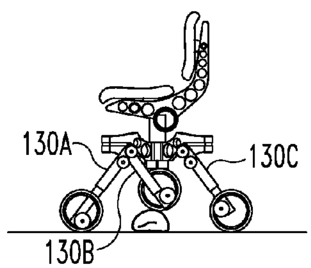
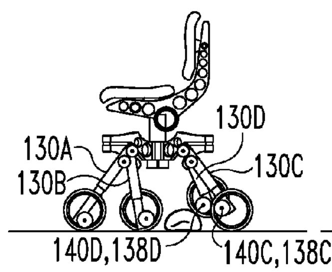


Fig. 15D



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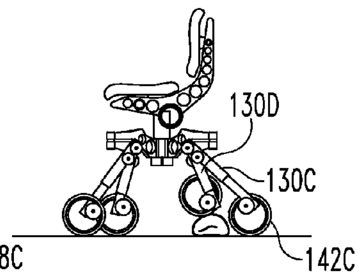

Fig. 15F

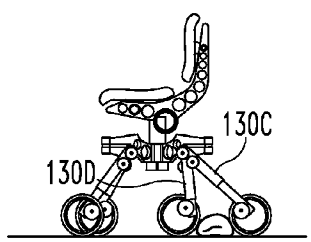

Fig. 15G

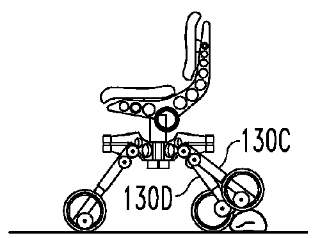

Fig. 15H

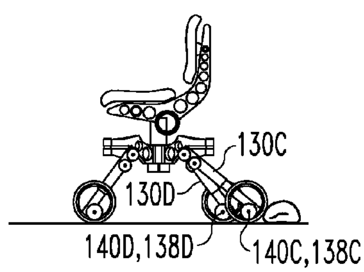

Fig. 15I

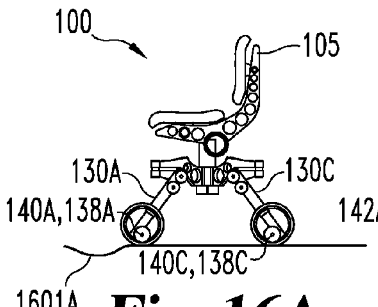

Fig. 16A

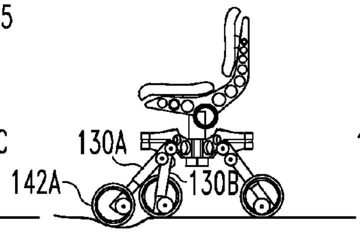

Fig. 16B

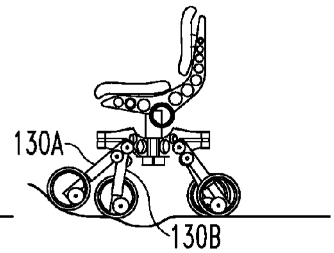

Fig. 16C

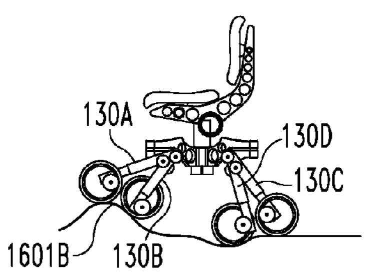

Fig. 16D

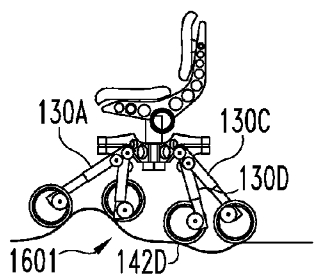

Fig. 16E

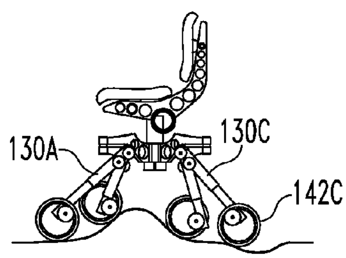

Fig. 16F

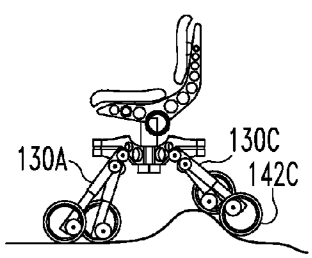

Fig. 16G

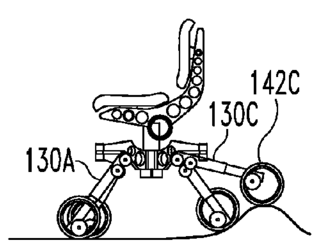

Fig. 16H

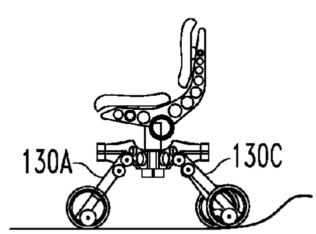

Fig. 16I

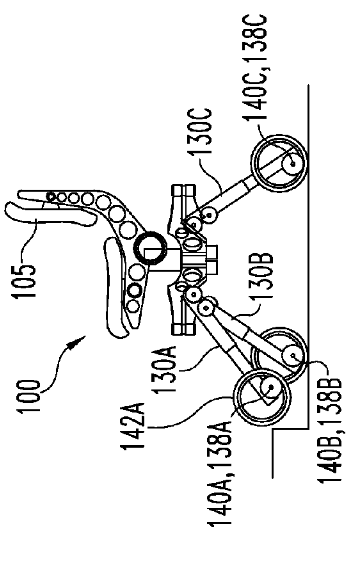

Fig. 17A

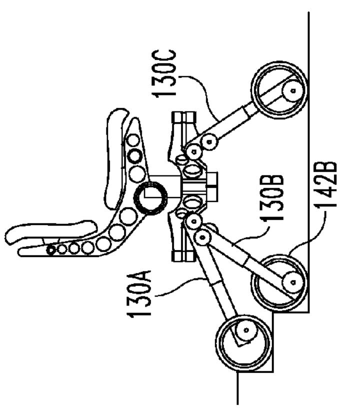

Fig. 17B

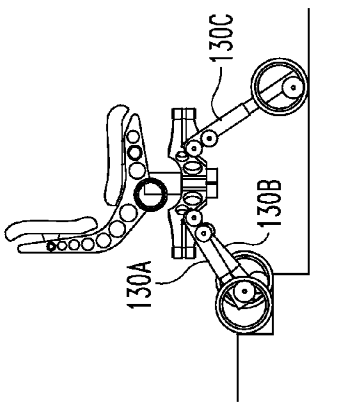

Fig. 17C

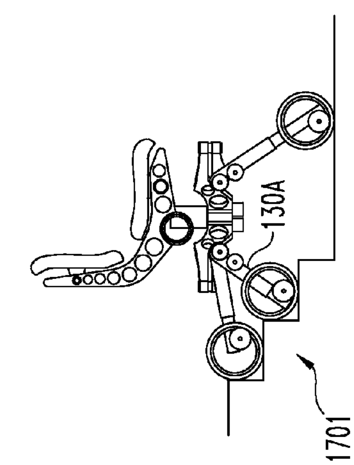

Fig. 17D

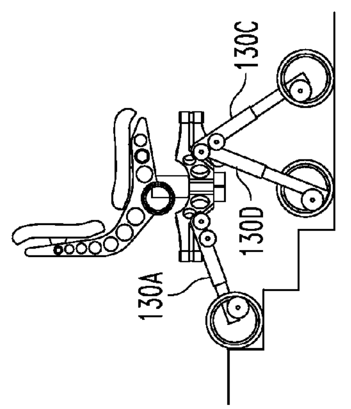

Fig. 17E

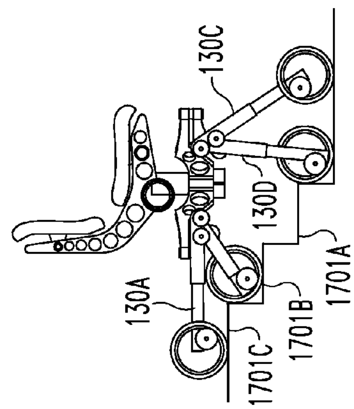

Fig. 17F

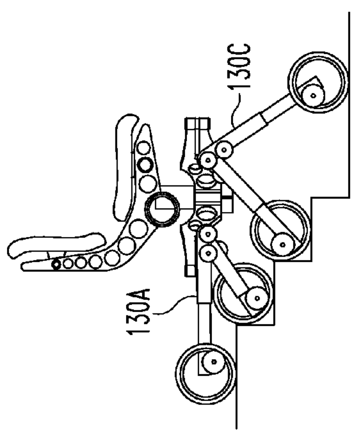

Fig. 17G

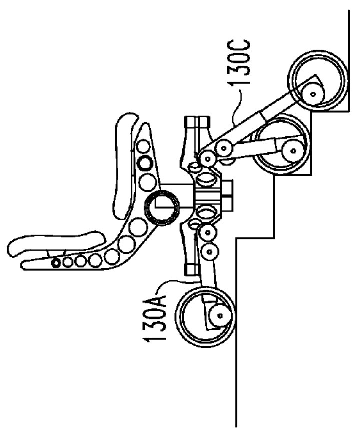

Fig. 17H

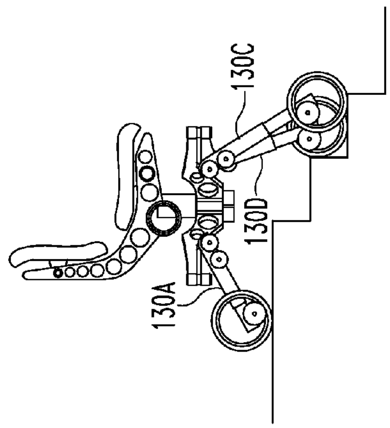

Fig. 17I

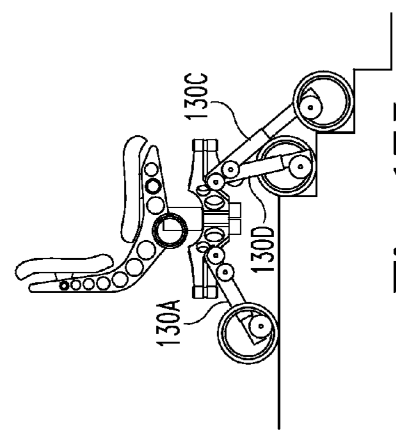

Fig. 17J

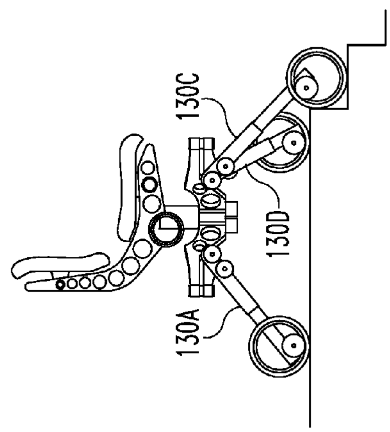

Fig. 17K

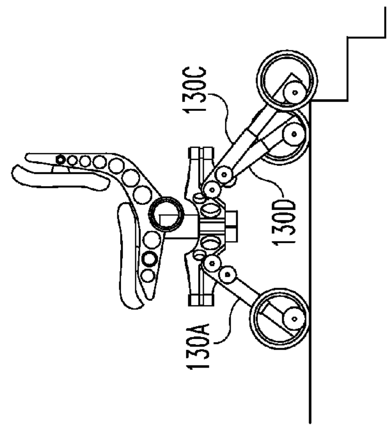

Fig. 17L

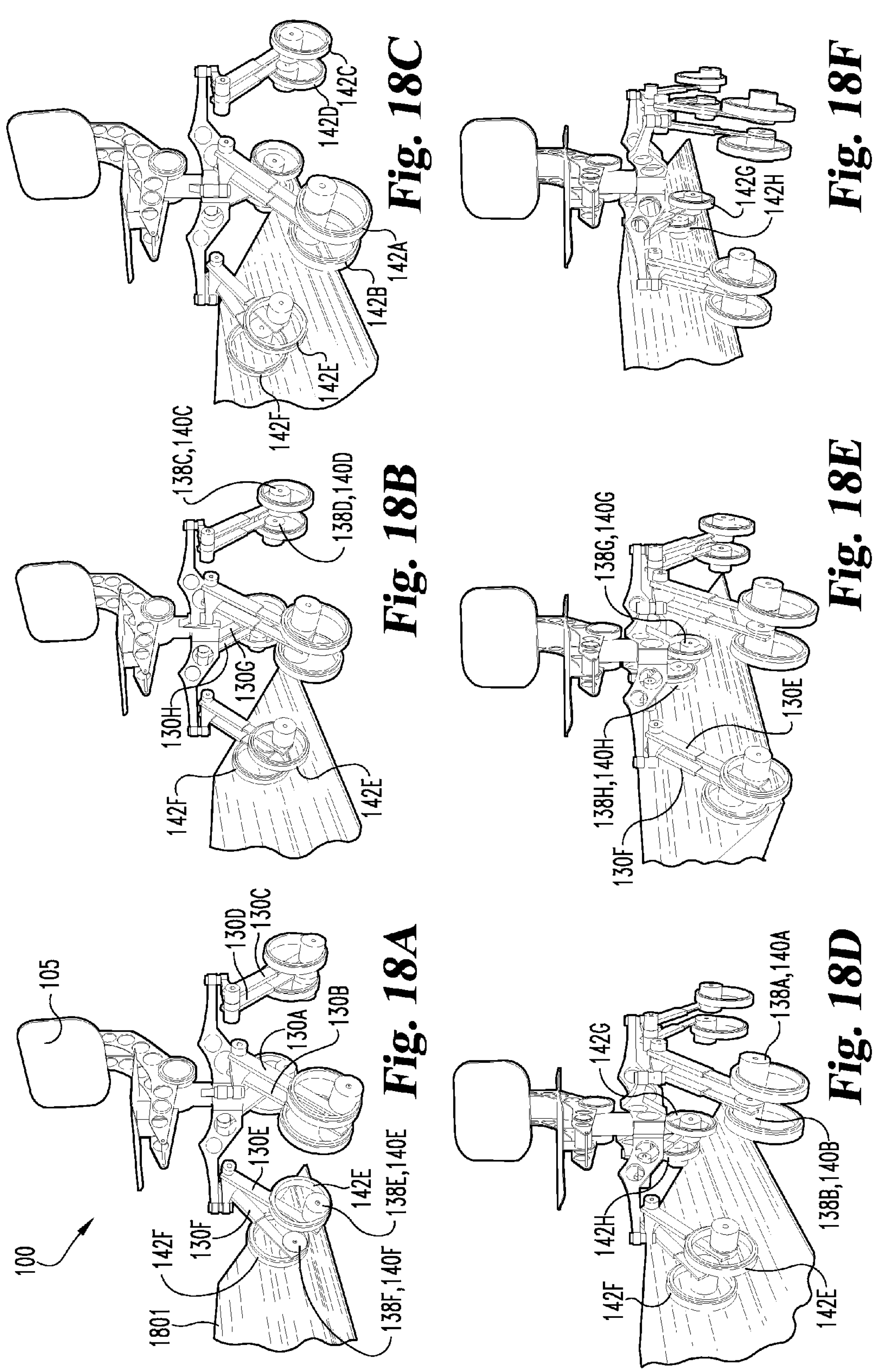

Fig. 18A

Fig. 18B

Fig. 18C

Fig. 18D

Fig. 18E

Fig. 18F

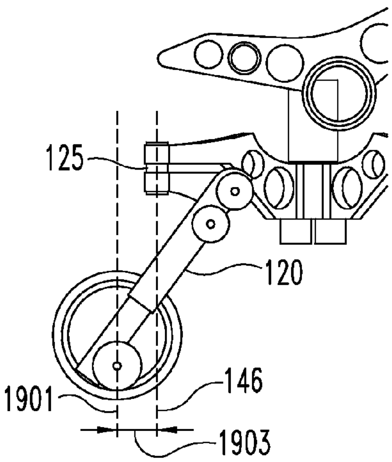

Fig. 19

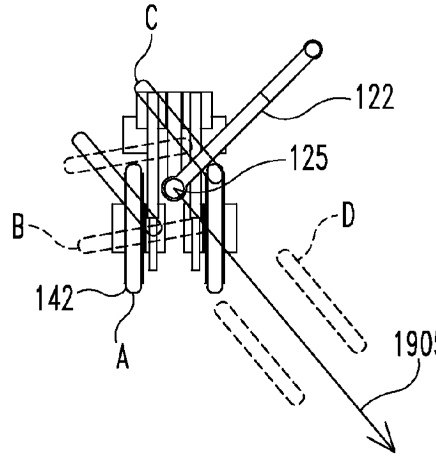

Fig. 20

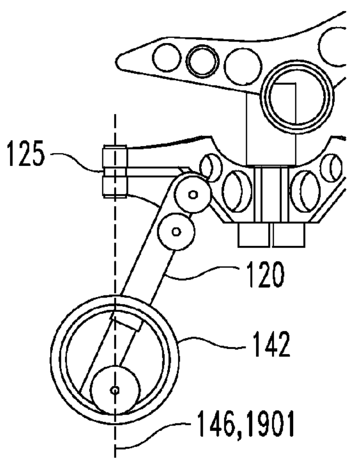

Fig. 21

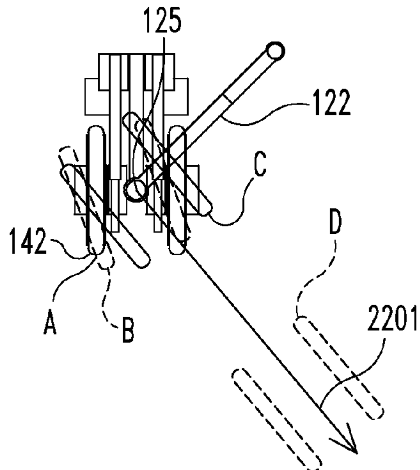

Fig. 22

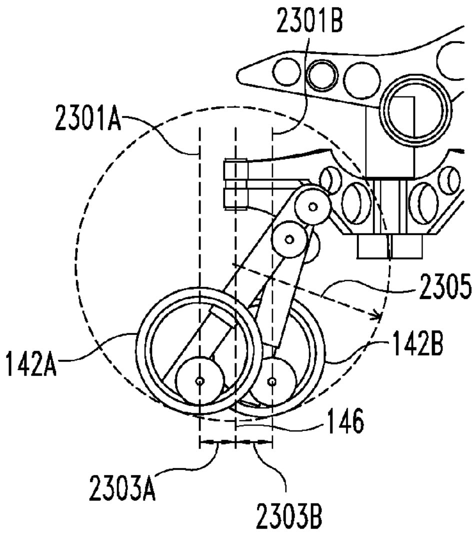

Fig. 23

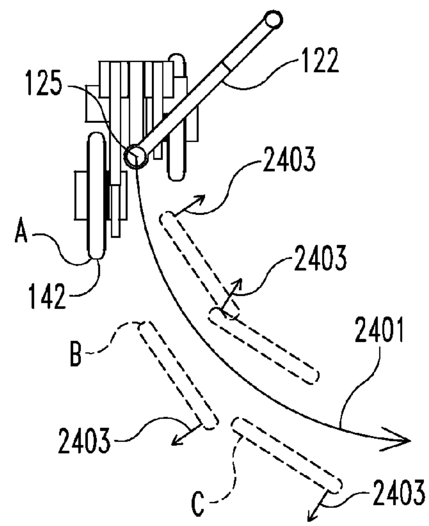

Fig. 24

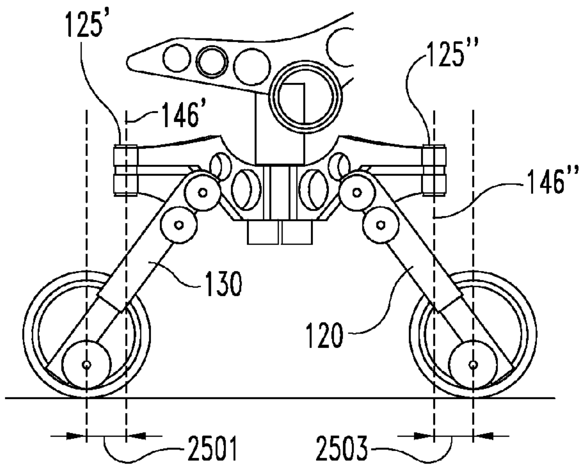

Fig. 25

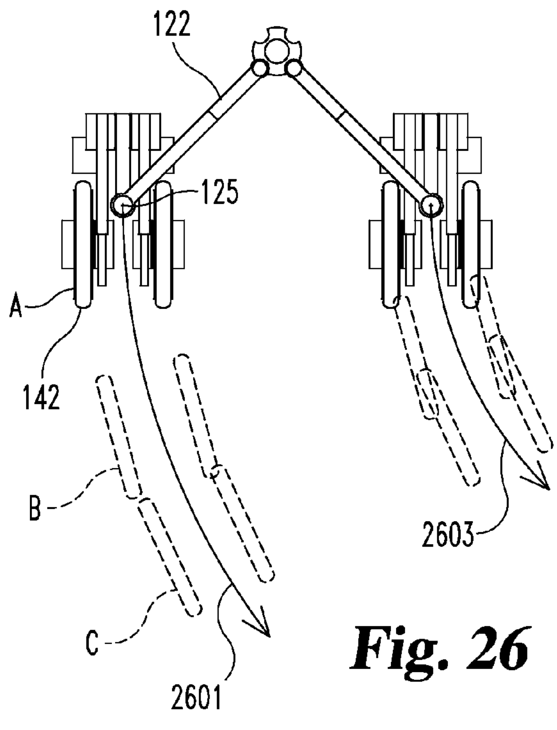

Fig. 26

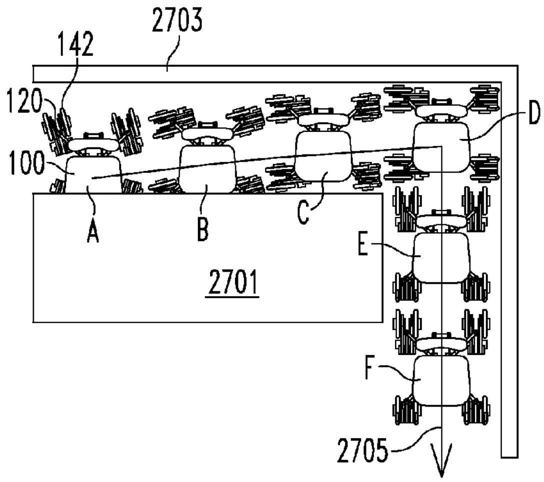

Fig. 27

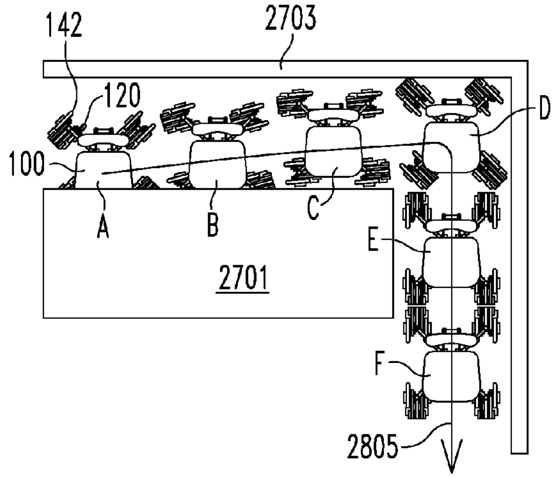

Fig. 28

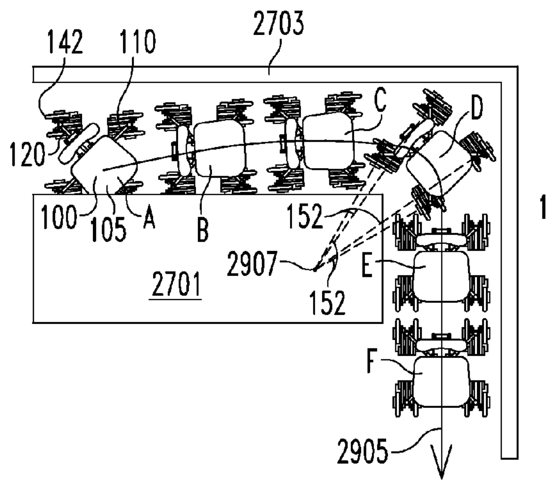

Fig. 29

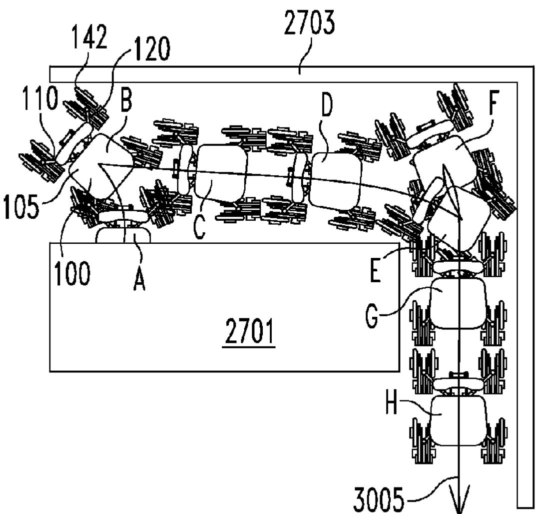

Fig. 30

ARTICULATED WHEEL ASSEMBLIES AND VEHICLES THEREWITH

[0001] This application is a continuation of PCT/US06/62107, filed Dec. 14, 2006, which claims the benefit of U.S. Provisional Application No. 60/755,625, filed Dec. 30, 2005, the entireties of which is hereby incorporated by reference. This application also claims the benefit of U.S. Provisional Application No. 60/755,625, filed Dec. 30, 2005, the entirety of which is hereby incorporated by reference.

FIELD

[0002] This invention relates generally to articulated wheel assemblies and vehicles therewith, and more particularly to moving wheeled vehicles, such as apparatuses, systems and methods for moving wheelchairs with articulated wheel assemblies.

BACKGROUND

[0003] Vehicles have been used to move various types of payloads. For example, rovers and remotely-operated wheeled vehicles have been used to carry sensors into environments dangerous or inhospitable to people. Other wheeled vehicles are used to assist people by moving various types of payloads, such as through a manufacturing plant. Still other wheeled vehicles, such as wheelchairs, are used as assistive devices to provide mobility to people who are otherwise limited in their ability to travel within their environment.

[0004] Many people throughout the world have physical restrictions that require them to use wheelchairs as their primary means of mobility. Although currently available assistive motion platforms allow their users to achieve a basic level of freedom, most users find their independence severely restricted by the mechanical and operational limitations of these devices. Unfortunately, even advanced wheelchairs can be stopped by a curb, step, irregular surface or small obstacle, and their ability to maneuver in tight spaces can be restricted by their physical configuration. These limitations can not only affect the ability of the user to freely access public and private spaces, but can make it difficult, if not impossible, to move about in an intuitive manner.

[0005] Others have attempted to address some of the concerns facing wheelchair users; however, the assistive devices that have been developed have limited functionality and can only be used in a small number of circumstances. For example, some wheelchairs are capable of omnidirectional-like movement, but are incapable of operating on anything other than a smooth, hard surface. Others are capable of traveling over rough terrain, but the extended wheelbases and oversized tires used to achieve this ability are too large for maneuvering in confined spaces.

[0006] As such, there is a need for a wheelchair that can function in an increased number of environments, traverse everyday obstacles, provide the natural movement patterns that many not confined to wheelchairs take for granted, and allow people who rely on wheelchairs for their mobility to focus their efforts on where they are going and not how they will get there.

[0007] Consequently, there is a need for an improved vehicle, an articulated wheel assembly, and in particular, an improved assistive mobility platform.

[0008] Certain preferred features of the present invention address these and other needs and provide other important advantages.

[0009] Some or all of these features may be present in the corresponding independent or dependent claims, but should not be construed to be a limitation unless expressly recited in a particular claim.

SUMMARY

[0010] It is an object of one embodiment of the present invention to provide improved articulated wheel assemblies and vehicles therewith.

[0011] It is an object of another embodiment of the present invention to provide an omnidirectional, obstacle climbing assistive device that provides quick, easy and natural movements, and can operate on smooth surface as well as uneven terrain.

[0012] It is an object of still another embodiment of the present invention to lower the vehicle's center of gravity to increase stability, such as may be required at high speeds or on uneven terrain, or raise its center of gravity, such as to provide the user with the ability to reach high locations.

[0013] It is an object of other embodiments of the present invention to traverse a wide variety of natural and man-made obstacles, for example, roadway curbs and steps, including steps approximately 12 inches high.

[0014] It is an object of yet another embodiment of the present invention to adjust the vehicle's track width to pass through both narrow obstacles, such as doorways, and to increase its stability to prevent tipping while maneuvering.

[0015] It is an object of still another embodiment of the present invention to provide intuitive motion to the user.

[0016] It is yet another object of embodiments of the present invention to maintain the seating system level and to keep the occupants securely attached to the vehicle while maneuvering.

[0017] It is still a further object of embodiments of the present invention to provide a vehicle including a payload platform and an offset link with a proximal end and a distal end. The offset link proximal end is pivotally connected with a vertically aligned pivot axis to the payload platform, and the offset link distal end is positioned a horizontal distance from the vertically aligned pivot axis. The vehicle also includes a first extendable member with a proximal end, a distal end, a first length and a first extension motor. The first extendable member proximal end is pivotally connected to the offset link distal end, where the first extension motor changes the first length, and where the first length and the vertically aligned pivot axis define a first swing angle. The vehicle further includes a first rotating motor connected to the first extendable member and the offset link, where the first rotating motor rotates the first extendable member and changes the first swing angle. The vehicle still further includes a first wheel with a first central axis, where the first wheel is rotatably connected to the first extendable member distal end. The vehicle additionally includes a first drive motor coupled to the first wheel, where the first drive motor rotates the first wheel around the first wheel central axis.

[0018] Another object of embodiments of the present invention provide a wheelchair for transporting a person across a surface that includes a seat for carrying a person and an articulated wheel assembly. The articulated wheel assembly includes an offset member with a proximal end and a distal end, the proximal end pivotally connected to the seat with a vertically aligned pivot axis, the distal end positioned a horizontal distance from the vertically aligned pivot axis. The articulated wheel assembly also includes an extendable member with a first opposing end, a second opposing end and a length, the extendable member first end connected to the offset member distal end, and the extendable member second end positioned on an opposite side of the vertical pivot axis from the offset member distal end. The articulated wheel assembly additionally includes an extension motor connected to the extendable member, where the extension motor changes the extendable member length; a wheel connected to the extendable member second end; and a propulsion motor connected to the wheel, where the propulsion motor rotates the wheel.

[0019] Yet another object of embodiments of the present invention provides a wheelchair for transporting a person across a surface that includes a seat for carrying a person and an articulated wheel assembly. The articulated wheel assembly includes an offset member with a proximal end and a distal end, the proximal end pivotally connected to the seat with a vertically aligned pivot axis, the distal end positioned a horizontal distance from the vertically aligned pivot axis. The articulated wheel assembly also includes an elongated member with a first opposing end, a second opposing end and a central axis between the first and second opposing ends, the elongated member first end connected to the offset member distal end. The articulated wheel assembly further includes a rotating motor connected to the offset member and the elongated member, where the rotating motor changes the angle between the vertically aligned pivot axis and the elongated member central axis. The articulated wheel assembly additionally includes a wheel connected to the elongated member second end and a propulsion motor connected to the wheel, where the propulsion motor rotates the wheel.

[0020] Further objects, features and advantages of the present invention shall become apparent from the detailed drawings and descriptions provided herein.

[0021] Each embodiment described herein is not intended to address every object described herein, and each embodiment does not include each feature described.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** is a side elevational view of wheelchair and articulated wheel assemblies according to one embodiment of the present invention.

[0023] FIG. **2** is a front elevational view of the wheelchair and articulated wheel assemblies of FIG. **1**.

[0024] FIG. **3**A is a top plan view of the wheelchair and articulated wheel assemblies of FIG. **1**.

[0025] FIG. **3**B is a partial top plan view of the wheelchair and articulated wheel assemblies of FIG. **3**B.

[0026] FIGS. **4**A-**4**F are side elevational views of an articulated wheel assembly depicted in FIG. **3**B.

[0027] FIGS. **5**A-**5**F are partial side elevational views of the wheelchair and an articulated wheel assembly depicted in FIG. **3**B.

[0028] FIGS. **6**A-**6**C are side elevational views of an articulated wheel assembly depicted in FIG. **3**B.

[0029] FIGS. **7**A-**7**I are partial side elevational views of the wheelchair and an articulated wheel assembly depicted in FIG. **3**B.

[0030] FIGS. **8**A-**8**F are top plan views of an articulated wheel assembly depicted in FIG. **3**B.

[0031] FIGS. **9**A-**9**F are top plan views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B.

[0032] FIGS. **10**A-**1O**F are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B.

[0033] FIGS. **11**A-**11**I are top plan views of the wheelchair, with the seat pan and back rest removed, and the articulated wheel assemblies depicted in FIG. **3**B.

[0034] FIGS. **12**A-**12**I are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a curb.

[0035] FIGS. **13**A-**13**I are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a gap.

[0036] FIGS. **14**A-**14**F are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a slope.

[0037] FIGS. **15**A-**15**I are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a limited size obstacle.

[0038] FIGS. **16**A-**16**I are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a rough terrain obstacle.

[0039] FIGS. **17**A-**17**L are side elevational views of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B traversing a stairway.

[0040] FIGS. **18**A-**18**F are perspective views of the wheelchair and articulated wheel assemblies of FIG. **3**B obliquely traversing a sloped surface.

[0041] FIG. **19** is a partial side elevational view of the wheelchair and an articulated wheel assembly depicted in FIG. **3**B in an omnidirectional wheel assembly configuration.

[0042] FIG. **20** is a top plan view of the articulated wheel assembly depicted in FIG. **19** depicting wheel movement.

[0043] FIG. **21** is a partial side elevational view of the wheelchair and an articulated wheel assembly depicted in FIG. **3**B in a virtual omnidirectional wheel assembly configuration.

[0044] FIG. **22** is a top plan view of the articulated wheel assembly depicted in FIG. **21** depicting wheel movement.

[0045] FIG. **23** is a side elevational view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B in a rough terrain wheel assembly configuration.

[0046] FIG. **24** is a top plan view of the articulated wheel assembly depicted in FIG. **23** depicting wheel movement.

[0047] FIG. **25** is a side elevational view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B in a differential wheel assembly configuration.

[0048] FIG. **26** is a top plan view of the articulated wheel assembly depicted in FIG. **25** depicting wheel movement.

[0049] FIG. **27** is a top plan view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B maneuvering using omnidirectional steering motion.

[0050] FIG. **28** is a top plan view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B maneuvering using synchronized steering motion.

[0051] FIG. **29** is a top plan view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B using independent all wheel steering.

[0052] FIG. **30** is a top plan view of the wheelchair and articulated wheel assemblies depicted in FIG. **3**B maneuvering using differential steering motion.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMODIMENTS

[0053] For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is hereby intended, such alterations and further modifications in the illustrated devices, and such further applications of the principles of the invention as illustrated herein being contemplated as would normally occur to one skilled in the art to which the invention relates.

[0054] The present invention relates to articulated wheel assemblies and vehicles utilizing articulated wheel assemblies. Example vehicles include wheelchairs, walkers, robots, motion platforms and remotely-operated vehicles that can carry various payloads, such as people, variously sized cargo, and sensing equipment by way on nonlimiting example. The size of the vehicle may be small, with overall dimensions less than one foot, and large, with overall dimensions on the order several to tens of feet.

[0055] Depicted in FIGS. **1-3** is an embodiment of the present invention, a vehicle or motion platform, for example, wheelchair **100**, according to one embodiment of the present invention. The wheelchair **100** includes a payload platform, for example seat **105**, for supporting the user and a motion base **110** that includes two or more wheel assembly support struts **122** (four wheel assembly support struts **122** in the illustrated embodiment) arranged around a central hub **124** to which the payload platform is rotatably attached.

[0056] Seat **105** includes frame **106**, seat pan **107**, back rest **108**, seat tilt pivot **109**, and arm rest **114**. Arm rest **114** includes a controller for commanding the wheelchair **100**, for example, joystick **115**. Attached to frame **106** is housing **102** that encloses battery **103** and microprocessor **104**. FIG. **3**B is similar to FIG. **3**A with housing **102**, arm rests **114**, and joystick **115** removed for illustrative purposes.

[0057] Seat pan **107** connects to seat pan tilt pivot **111**, which connects to frame **106** and allows the user to tilt seat pan **107** with respect to frame **106** for user comfort. Back rest **108** connects to back rest tilt pivot **112**, which connect to frame **106** and allows the user to adjust the tilt of back rest **108** with respect to frame **106** for user comfort.

[0058] Seat **105** connects to seat tilt pivot **109**, which connects to seat adjustment mechanism **116**. Seat tilt pivot **109** allows the user to adjust the seat tilt with respect to the motion base **110** for user comfort. Seat adjustment mechanism **116** allows the user to raise, lower, and/or pivot seat **105** with respect to motion base **110**. In the illustrated embodiment, seat adjustment mechanism **116** is powered by battery **103**, although in alternate embodiments, seat adjustment mechanism **116** is a manually-adjusted mechanism and is not powered.

[0059] Seat adjustment mechanism **116** is connected to central hub **124**. Wheel assembly support strut pivots **123** pivotally connect the wheel assembly support struts **122** to central hub **124**. In the illustrated embodiment, wheel assembly support strut pivot **123** allows wheel assembly support strut **122** to pivot with minimal resistance. In an alternate embodiment, wheel assembly support strut pivot **123** is selectively lockable and capable of restraining wheel assembly support strut **122** in a particular orientation with respect to central hub **124**. In still another embodiment, wheel assembly support strut pivot **123** is further connected to a wheel assembly support strut pivot actuator **126**, which applies force to wheel assembly support strut **122** and actively changes the orientation of wheel assembly support strut **122** with respect to central hub **124**. In FIGS. **1** and **2**, wheel assembly support strut pivot actuator **126** is illustrated with dashed lines to indicate an example location where the wheel assembly support strut pivot actuators **126** are located in an alternate embodiment.

[0060] Each wheel assembly support strut **122** is rotatably connected by a vertical wheel assembly pivot **125** to an offset link, for example offset connecting arm **128**. Each articulated wheel assembly **120** includes offset connecting arm **128**, two linear actuators **130**, two upper rotary actuators **135**, two linear actuator motors **136**, two lower rotary actuators **138**, two propulsion motors **140**, and two wheels **142**. The linear actuator **130** includes an upper portion **131** and a lower portion **132** that move with respect to one another to extend or retract the effective length **150** of linear actuator **130**. The wheel **142** includes a wheel outer surface **143** and a wheel drive portion **144**.

[0061] Each offset connecting arm **128** rotatably connects to a wheel assembly support strut **122** with a vertical wheel assembly pivot **125**. In the illustrated embodiment, offset connecting arm **128** pivots around vertical wheel assembly pivot axis **146** principally in response to forces exerted on the surface **156** by wheels **142**. In an alternate embodiment, vertical wheel assembly pivot **125** includes a clutch or detent mechanism that provides for the locking of offset connecting arm **128** in at least one position with respect to wheel assembly support strut **122**. In still another embodiment, vertical wheel assembly pivot **125** includes an actuator that applies a force to rotate offset connecting arm **128** with respect to wheel assembly support strut **122**.

[0062] Offset connecting arm **128** is connected to two upper rotary actuators **135** and each upper rotary actuator **135** is connected to a linear actuator **130**. Each upper rotary actuator **135** applies a rotational force to its respective linear actuator **130** and can rotate linear actuator **130** around upper rotary actuator axis **148** or can hold linear actuator **130** at a constant rotational position with respect to offset connecting arm **128**. In an alternate embodiment, the two upper rotary actuators **135** for each articulated wheel assembly **120** may be combined into a single unit that can independently rotate each of the two linear wheel actuators **130**.

[**0063**] Each linear actuator **130** includes means for extending and retracting linear actuator **130**, for example, a linear actuator motor **136** that can extend, shorten or hold constant the linear actuator effective length **150**. In the illustrated embodiment, linear actuator **130** includes telescoping upper and lower portions **131** and **132**, respectively; however, in other embodiments a sliding or other arrangement is used to provide for the lengthening, shortening or holding constant of linear actuator effective length **150**.

[**0064**] Each linear actuator **130** is connected to a lower rotary actuator **138**, which is further connected to a wheel **142**. The lower rotary actuator **138** rotates wheel rotation axis **152** around wheel pivot axis **154**. As such, the orientation of wheel **142** with respect to linear actuator **130** may be changed or held constant during operation.

[**0065**] Adjacent to lower rotary actuator **138** is propulsion motor **140** which is connected to wheel drive portion **144** and rotates wheel **142** about wheel rotation axis **152**. In the illustrated embodiment, the wheel **142** and propulsion motor **140** are arranged as a "hubless wheel," although in other embodiments a more conventional hubbed wheel and associated propulsion motor are used. Propulsion motor **140** is connected to and imparts the drive force to wheel drive portion **144**. Wheel drive portion **144** is connected to wheel outer surface **143** which contacts surface **156**. In alternate embodiments, at least one articulated wheel assembly **120** does not include a propulsion motor **140** and the wheel **142** passively rotates in response to the motion of wheelchair **100**.

[**0066**] Although each articulated wheel assembly **120** is depicted with two linear actuators **130** and two wheels **142**, alternate embodiments include one linear actuator **130** and one wheel **142**. Additionally, alternate embodiments include a rigid attachment between offset connecting arm **128** and linear actuator **130**. Still further embodiments include a linear actuator **130** with a fixed linear actuator effective length **150**. Yet, further embodiments connect linear actuator **130** directly to propulsion motor **140**, resulting in a set orientation between wheel rotation axis **152** and linear actuator **130**.

[**0067**] Wheelchair **100** further includes at least one battery **103** and at least one microprocessor **104**. Housing **102** encloses the illustrated battery **103** and microprocessor **104**. Battery **103** is connected to and provides power to microprocessor **104** and the various actuators and motors in wheelchair **100**. Battery **103** includes a means for recharging, such as a cord that may plug into a typical household outlet. Microprocessor **104** controls the various actuators, motors and sensors included with wheelchair **100**. Microprocessor **104** receives input from the user, and the sensors **113** if present, and calculates the appropriate commands to send to the various actuators and motors to achieve the motion desired by the user. Microprocessor **104** may be connected to the actuators and motors using different means of communication, for example, electrical wires, fiber optic cables, and wireless communication. Although depicted as attached to a wheel assembly support strut **122**, alternate embodiments of wheelchair **100** include sensors located at different locations on wheelchair **100** to provide environmental and operational sensing for the user and/or microprocessor.

[**0068**] The term sensor describes a device that detects a physical stimulus, for example, a device that ascertains the presence of an obstacle and is used by the motion platform to traverse the obstacle. Example sensors include devices utilizing ultrasonic, infrared, laser, television, and charged coupled device technologies as well as others that are capable of detecting the presence of an obstacle. Alternate embodiments do not include sensors and rely on input commands from the user to negotiate obstacles. Still other embodiments utilize a combination of sensors and inputs from the user to negotiate obstacles, for example, the user selecting a particulate mode, such as a narrow passage negotiation mode, and the sensors being utilized in response to the mode selection in order to carry out the desired function.

[**0069**] Although the four articulated wheel assemblies **120** depicted in the illustrated embodiment are similarly sized and configured, alternate embodiments include articulated wheel assemblies **120** with alternate dimensions and alternate numbers of components. For example, one alternative embodiment includes front wheels **142** that are smaller than rear wheels **142**. Another alternate embodiment includes front articulated wheel assemblies **120** with a single linear actuator **130** and a single wheel **142**, while the rear articulated wheel assemblies **120** include two linear actuators **130** and two wheels **142**.

[**0070**] In the illustrated embodiment, the linear actuator effective length **150** can be changed during operation by linear actuator motor **136**. Longer linear actuator effective length **150** can result in the ability for wheelchair **100** to achieve greater stability, although the longer linear actuator effective length **150** generally increases the stresses on upper rotary actuator **135**, or on the connection between linear actuator **130** and the wheel assembly support strut **122** in embodiments where there is a fixed linear actuator swing angle **170**. During operation, the linear actuator effective length **150** can vary from six (6) inches to thirty-six (36) inches. In particular, the linear actuator effective length **150** can vary from nine (9) inches to thirty (30) inches during operation, and more particularly the linear actuator effective length **150** can vary from twelve (12) inches to twenty-four (24) inches during operation. It should be appreciated that linear actuator **130** can include three or more portions that move with respect to one another to extend or retract the effective length **150**.

[**0071**] In an alternate embodiment, linear actuator effective length **150** is fixed and can range from six (6) inches to eighteen (18) inches. In the fixed linear actuator effective length **150** embodiment, the length **150** can particularly range from ten (10) inches to fourteen (14) inches, and can more particularly equal approximately twelve (12) inches.

[**0072**] In the illustrated embodiment, the offset connecting arm effective length **158** can range from zero (0) to eight (8) inches. A longer offset connecting arm effective length **158** can require the use of longer wheel assembly support struts **122**, thereby increasing the overall dimensions of wheelchair **100**, and will increase the stresses on vertical wheel assembly pivot **125**. However, a longer offset connecting arm effective length **158** allows the use of longer linear actuators **130** and without increasing the overall dimensions of wheelchair **100**, and increases the overall stability that may be achieved by wheelchair **100**. Increased linear actuator effective length **150** provides an increased ability for articulated wheel assemblies **120** to clear or traverse obstacles. The offset connecting arm effective length **158** can more particularly range from two (2) to six (6) inches, and more particularly, the offset connecting arm effective length **158** equals approximately four (4) inches.

[**0073**] The wheel height or diameter **160** can range from three (3) to fifteen (15) inches in the illustrated embodiment. A wheel **142** with a larger wheel diameter **160** can more easily roll over obstacles, although a larger wheel diameter **160** can limit the maneuverability of wheelchair **100** and create clearance difficulties with the other elements of articulated wheel assembly **120** and the user. The wheel diameter **160** can particularly range from six (6) inches to ten (10) inches, and more particularly the wheel diameter **160** equals approximately eight (8) inches.

[**0074**] The offset distance **162** between wheel rotation axis **152** and wheel pivot axis **154** can range from zero (0) inches to eight (8) inches in the illustrated embodiment. A larger offset distance **162** enables wheelchair **100** to increase the distance that wheel **142** can extend away from seat **105**, although a larger offset distance **162** increases the forces on lower rotary actuator **138**. The offset distance **162** can particularly range from two (2) inches to six (6) inches, and the offset distance **162** can more particularly equal approximately four (4) inches.

[**0075**] Although the four articulated wheel assemblies **120** depicted in the illustrated embodiment are similarly sized and configured, alternate embodiments include articulated wheel assemblies **120** with different dimensions and different numbers of components.

[**0076**] In the illustrated embodiment, the wheel offset distance **165** can range from two (2) inches to ten (10) inches. The wheel offset distance **165** can particularly range from four (4) inches to eight (8) inches, and the wheel offset distance **165** can more particularly equal approximately six (6) inches.

[**0077**] The wheel assembly support strut effective length **168** equals the distance between the central axis **129** of the central hub **124** and the vertical wheel assembly pivot axis **146**. The wheel assembly support strut effective length **168** is depicted in both FIGS. **1** and **2**, although FIG. **1** obliquely depicts wheel assembly support strut **122** wheel assembly support strut effective length **168**. As the wheel assembly support strut effective length **168** increases, the overall stability that may be achieved by wheelchair **100** increases. As the wheel assembly support strut effective length **168** decreases, the overall stability that may be achieved by wheelchair **100** decreases. The wheel assembly support strut effective length **168** in the illustrated embodiment can range from six (6) inches to eighteen (18) inches. The wheel assembly support strut effective length **168** can particularly range from twelve (12) inches to sixteen (16) inches, and the wheel assembly support strut effective length **168** can more particularly equal approximately fourteen (14) inches.

[**0078**] In an alternate embodiment, a plate (not depicted) to which the vertical wheel assembly pivots **125** are connected is used in lieu of the offset connecting arms **128**. Use of the plate simplifies the structure of wheelchair **100**, which can make wheelchair **100** easier to manufacture than embodiments using the wheel assembly support struts **122**. However, the use of a plate removes the ability of wheel assembly support struts **122** to pivot around wheel assembly support strut pivots **123**.

[**0079**] In embodiments where the offset connecting arm effective length **158** is zero, the offset connecting arm **128** is effectively eliminated and the upper rotary actuators **135** are located adjacent the wheel assembly pivots **125**.

[**0080**] The linear actuator swing angle **170** indicates the extent to which linear actuator **130** is angled. The linear actuator swing angle **170** is the angle between the linear actuator axis **172** and the motion base reference plane **174**, and is measured between the offset connecting arm **128** and the linear actuator **130**. The angular difference between the motion base reference plane **174** and the surface **156** indicates the tilt of the wheel assembly support struts **122** with respect to surface **156**. As the linear actuator swing angle **170** approaches 0 or 180 degrees, the torque required by upper rotary actuator **135** to either hold steady or rotate the linear actuator **130** increases. In the illustrated embodiment, the linear actuator swing angle **170** can range from negative **20** (−20) degrees to 200 degrees. The linear actuator swing angle **170** can more particularly range from 20 degrees to 160 degrees. In alternate embodiments, linear actuator swing angle **170** is fixed, and can range from 10 to 90 degrees, and can particularly range from 30 to 70 degrees, and can more particularly equal approximately 55 degrees.

[**0081**] Although the linear actuator swing angle **170** is described in the illustrated embodiment as being the angle between the linear actuator axis **172** and the motion base reference plane **174** as measured between the offset connecting arm **128** and the linear actuator **130**, this is a measurement convention used to illustrate the motion and orientation of linear actuator **130** and should not be considered restrictive in nature. Other measurement conventions may be used to describe the motion and orientation of linear actuator **130**, for example, defining the swing angle as the angle between the linear actuator axis **172** and the vertical wheel assembly pivot axis **146**.

COMPONENT MOVEMENTS

[**0082**] The following section depicts example component movements of articulated wheel assemblies **120**. By combining the component movements, more complicated operations are achieved. Although the example movements are generally depicted as occurring in one direction, it should be understood that the depicted articulated wheel assemblies **120** are capable of movement in at least the direction opposite to that depicted.

[**0083**] FIGS. **4A-4F** depict the interaction between lower rotary actuator **138** and wheel **142**. Movement arrow **401** is indicative of the rotation direction of wheel **142** around lower rotary actuator **138**. As can be seen by the drawings, the rotation of wheel **142** by lower rotary actuator **138** results in wheel rotation axis **152** rotating around wheel pivot axis **154**.

[**0084**] FIGS. **5A-5F** depict the interaction between upper rotary actuator **135** and linear actuator **130**. Movement arrow **501** is indicative of the swing direction of linear actuator **130** around upper rotary actuator **135**.

[0085] FIGS. **6**A-**6**C depict the extension of linear actuator **130**. Movement arrow **601** is indicative of the extension of linear actuator **130**.

[0086] FIGS. **7**A-**7**I depict a sequential combination of motions that are represented in FIGS. **4**-**6**. Although these component movements are depicted as sequential, it should be appreciated that at least two of the depicted component movements may be performed simultaneously. It should be further appreciated that the depicted sequence order is not limiting, and that other sequences and sequence orders are contemplated and included. In FIGS. **7**A-**7**C linear actuator **130** rotates forward, as indicated by movement arrow **501**. Once rotation of linear actuator **130** stops, linear actuator **130** extends, then lower rotary actuator rotates wheel **142**.

[0087] FIGS. **7**A-**7**I illustrate example movements of the articulated wheel assemblies **120** that may be used to overcome various types of obstacles and terrain. Alternate embodiments use different movement sequences of the articulated wheel assemblies **120** and other components to overcome obstacles and traverse uneven terrain.

[0088] FIGS. **8**A-**8**F depict the rotation of articulated wheel assembly **120** around vertical wheel assembly pivot **125**. Movement arrow **801** is indicative of the rotation direction of articulated wheel assembly **120**.

[0089] FIGS. **9**A-**9**F depict the rotation of seat **105** with respect to the wheel assembly support struts **122**. Movement arrow **901** is indicative of the rotation direction of seat **105**.

COMBINED COMPONENT MOTION CAPABILITIES

[0090] FIGS. **10**-**18** depict example combined component motion sequences that may be used to overcome the depicted obstacles and terrain. These combined component motion sequences are considered exemplary in nature and are used for illustrative purposes to describe the various types of combined component motion sequences the articulated wheel assemblies **120** are capable of executing. The actual sequence of movements executed when wheelchair **100** encounters an obstacle can vary considerably depending on the specific motion strategies chosen in response to localized factors and operational considerations.

[0091] FIGS. **10**A-**10**F depict wheelchair **100** increasing the height of seat **105** by manipulation of the articulated wheel assemblies **120**. FIG. **10**A depicts this seat **105** in a lower position with upper rotary actuators **135** maintaining linear actuators **130** approximately parallel to surface **156**. As upper rotary actuators **135** rotate linear actuators **130** downward, the distance between seat **105** and surface **156** increases. To control the initial torque required by upper rotary actuators **135**, wheels **142** are initially drawn inward with the retraction of linear actuators **130**. As linear actuators **130** rotate downward, the linear actuators **130** begin to extend to increase the height of seat **105** above surface **156**. To further increase the height of seat **105** above surface **156**, lower rotary actuators **138** rotate wheel **142** downward.

[0092] Depicted in FIGS. **11**A-**11**I, is wheelchair **100'** (wheelchair **100** with seat pan **107** and back rest **108** removed for illustrative purposes) while moving through a narrow passageway. As wheelchair **100'** approaches the narrow obstacle **1101**, the forward articulated wheel assemblies **120** move close together by initially angling toward one another then realigning along the direction of travel as obstacle **1101** is approached. The inward angling of articulated wheel assemblies **120** occurs between the depictions in FIGS. **11**A and **11**B. In embodiments where wheel assembly support strut pivot **123** is lockable, the lock must be disengaged before wheel assembly support struts **122** may rotate. In embodiments where wheel assembly support strut pivot **123** is not lockable, wheel assembly support struts **122** rotate inward in response to the movements of articulated wheel assemblies **120**. After each pair or articulated wheel assemblies **120** passes through narrow obstacle **1101**, the articulated wheel assemblies **120** in each pair angle outward and increase their horizontal separation, as depicted between FIGS. **11**D and **11**E for the front pair of articulated wheel assemblies **120**, and between FIGS. **11**H and **11**I for the rear pair of articulated wheel assemblies **120**. After passing through narrow obstacle **1101**, wheelchair **100'** is substantially in the same configuration wheelchair **100'** was in prior to passing through narrow obstacle **1101**. In alternate embodiments, both pairs of articulated wheel assemblies **120** may narrow simultaneously when approaching a narrow obstacle **1101**. In the illustrated embodiment, sensors **113** mounted on wheelchair **100'** (see FIG. **3**B) automatically detect the requirement to narrow the wheelbase of wheelchair **100'** as wheelchair **100'** approaches the narrow obstacle **1101**, and the wheelchair **100'** automatically narrows its wheelbase in response to this requirement. In other embodiments, the user inputs a command to wheelchair **100'** to reconfigure into a configuration with a narrower wheelbase as wheelchair **100'** approaches narrow obstacle **1101**.

[0093] In alternate embodiments, pressure transducers located within articulated wheel assemblies **120** detect forces acting on articulated wheel assemblies **120**. For example, in an alternate embodiment upper rotary actuator **135** and linear actuator motor **136** include pressure transducers to detect forces imparted to linear actuator **130** by surface **156** or various obstacles. In embodiments of the present invention, the components of articulated wheel assemblies **120** respond to these external forces, for example, linear actuator **130** retracts when encountering a force applied to linear actuator **130** by an external obstacle such as curb **1201** (FIG. **12**).

[0094] FIG. **3**B includes a depiction of the individual components illustrated and discussed in FIGS. **12**-**18**, which include linear actuators **130**A-**130**H, upper rotary actuators **135**A-**135**H, lower rotary actuators **138**A-**138**H, propulsion motors **140**A-**140**H, and wheels **142**A-**142**H.

[0095] FIGS. **12**A-**12**I depict wheelchair **100** traversing a vertical obstacle, such as curb **1201**. When traversing obstacles, for example curb **1201**, the motion of the articulated wheel assemblies **120** can resemble a person "stepping" over the obstacle. As wheelchair **100** approaches curb **1201**, sensors, for example infrared or ultrasonic sensors, detect the approaching curb **1201** and wheelchair **100** performs the depicted example movements to traverse curb **1201**. Although two articulated wheel assemblies **120** are depicted (the forward-left and rearward-left articulated wheel assemblies **120**), it should be understood that the two remaining articulated wheel assemblies **120** (the forward-right and the rearward-right articulated wheel assemblies **120**) are moving in a similar fashion. Additionally, as each articulated wheel assembly **120** includes two linear actuators

130, two lower rotary actuators **138**, two propulsion motors **140**, and two wheels **142**, the forward-outboard components are labeled with an "A," the forward-inboard components are labeled with a "B," the rear-outboard elements are labeled with a "C," and the rear-inboard components are labeled with a "D." For example, the forward-outboard linear actuator **130** is labeled actuator **130**A, and the rear-outboard linear actuator **130** is labeled linear actuator **130**C (see FIG. **3**B).

[**0096**] As wheelchair **100** approaches curb **1201**, linear actuator **130**A rotates upward and lower rotary actuator **138**A rotates wheel **142**A forward. Once wheel **142**A is positioned on the upper surface of curb **1201**, linear actuator **130**B retracts, rotates rearward, and, as the wheelchair **100** continues to more forward, places wheel **142**B on top of curb **1201** (FIGS. **12**C and **12**D). As wheelchair **100** moves onto curb **1201**, seat **105** is raised and the rearward linear actuators **130**C and **130**D extend to maintain seat **105** level. As the rearward linear actuators **130** approach curb **1201**, the rear-outboard linear actuator **130**C retracts and lower rotary actuator **138**C rotates wheel **142**C forward. With wheel **142**C on top of curb **1201**, linear actuator **130**D retracts and lower rotary actuator **138**D rotates wheel **142**D forward (FIGS. **12**F-**12**H). Once on top of curb **1201** (FIG. **12**I), wheelchair **100** returns to a configuration similar to the configuration at the beginning of the sequence (FIG. **12**A).

[**0097**] Depicted in FIGS. **13**A-**13**I is wheelchair **100** traversing a gap **1301**. As wheelchair **100** approaches gap **1301**, linear actuator **130**A extends and lower rotary actuator **138**A rotates wheel **142**A forward until wheel **142**A is positioned on the other side of gap **1301** (FIGS. **13**A-**3**C). Once wheel **142**A is positioned on the other side of gap **1301**, linear actuator **130**B extends and rotates forward to place wheel **142**B on the far side of gap **1301** (FIGS. **13**C-**13**E). As the rear wheels approach gap **1301**, linear actuator **130**D retracts and rotates forward to move wheel **142**D across gap **1301**. As wheel **142**D crosses gap **1301**, linear actuator **130**C extends and lower rotary actuator **138**C rotates wheel **142**C rearward. Once wheel **142**D has traversed gap **1301**, linear actuator **130**C retracts and lower rotary actuator **138**C rotates wheel **142**C forward (FIGS. **13**G-**13**I). After traversing gap **1301** (FIG. **13**I), wheelchair **100** is configured similarly to the configuration prior to executing the illustrated sequence (FIG. **13**A).

[**0098**] Additionally, FIGS. **14**A-**14**F depict wheelchair **100** traversing a slope **1401**. As wheelchair **100** begins up slope **1401**, the forward linear actuators **130**A and **130**B retract while the rearward linear actuators **130**C and **130**D extend in order to maintain seat **105** level (FIGS. **14**A-**14**C). The rearward lower rotary actuators **138**C and **138**D rotate wheels **142**C and **142**D downward to maintain seat **105** level. As wheelchair **100** moves beyond slope **1401** and onto a level surface, the forward linear actuators **130**A and **130**B extend and the rearward linear actuators **130**C and **130**D retract while lower rotary actuators **138**C and **138**D rotate wheels **142**C and **142**D forward (FIGS. **14**D-**14**F). Upon completing the sequence (FIG. **14**F), wheelchair **100** is in a similar configuration as when wheelchair **100** began the sequence (FIG. **14**A).

[**0099**] FIGS. **15**A-**15**I depict wheelchair **100** as it traverses a limited size obstacle on surface **156**, for example rock **1501**. As wheelchair **100** approaches rock **1501**, linear actuator **130**A extends and rotates forward until wheel **142**A contacts rock **1501**. As wheel **142**A rolls over rock **1501**, linear actuator **130**A extends and lower rotary actuator **138**A rotates wheel **142**A forward (FIGS. **15**A-**15**C). As wheel **142**B contacts rock **1501**, linear actuator **130**B retracts and rotates rearward to maintain contact between wheel **142**B and surface **156** (FIGS. **15**B and **15**C). As wheel **142**B rotates over rock **1501**, linear actuator **130**B initially retracts then extends (FIGS. **15**C-**15**E). As the rear wheels approach rock **1501**, linear actuator **130**D retracts and rotates forward. As wheel **142**D rotates over rock **1501**, linear actuator **130**D initially retracts and then extends while lower rotary actuator **138**D rotates wheel **142**D forward as wheel **142**D again comes into contact with surface **156** (FIGS. **15**E-**15**G). Linear actuator **130**C extends and rotates rearward while lower rotary actuator **138**C rotates wheel **142**C downward to maintain contact with surface **156** (FIGS. **15**E and **15**F). As wheel **142**C rotates over rock **1501**, linear actuator **130**C initially retracts then extends as lower rotary actuator **138**C rotates wheel **142**C over rock **1501** (FIGS. **15**F-**15**I).

[**0100**] FIGS. **16**A-**16**I depict wheelchair **100** traversing rough terrain obstacle **1601**, which includes depression **1601**A and bump **1601**B. As wheelchair **100** traverses depression **1601**A, linear actuator **130**A extends and rotates forward while lower rotary actuator **138**A rotates wheel **142**A forward (FIGS. **16**A and **16**B). As wheel **142**A climbs bump **1601**B, linear actuator **130**A rotates forward and lower rotary actuator **138**A rotates wheel **142**A forward. As wheel **142**A travels downward after crossing the apex of bump **1601**B, lower rotary actuator **138**A rotates wheel **142**A downward and linear actuator **130**A extends further (FIGS. **16**D-**16**F). Linear actuator **130**C and **130**D extend to maintain seat **105** in a level orientation as wheels **142**A and **142**B traverse bump **1601**B (FIGS. **16**D-**16**F). As wheel **142**D traverses bump **1601**B, linear actuator **130**D retracts then extends. As wheel **142**C traverses bump **1601**B, linear actuator **130**C remains extended and lower rotary actuator **138**C rotates wheel **142**C forward (FIGS. **16**F-**16**I). The linear and rotary actuators move in a coordinates fashion to provide clearance for the components of wheelchair **100** and to maintain stability.

[**0101**] Depicted in FIGS. **17**A-**17**F, wheelchair **100** traverses a stairway **1701**, which includes first step **1701**A, second step **1701**B, and third step **1701**C. As wheelchair **100** approaches stairway **1701**, linear actuator **130**A rotates forward and extends, and lower rotary actuator **138**A rotates wheel **142**A forward. With wheel **142**A established atop first step **1701**A, linear actuator **130**B retracts as wheel **142**B climbs first step **1701**A (FIGS. **17**A and **17**B). Linear actuators **130**C and **130**D extend to maintain seat **105** in a level orientation and seat **105** rotates to face rearward to allow the user's legs to extend downward without contacting with the articulated wheel assemblies **120** (FIGS.**17**A-**17**C). As wheelchair **100** continues up stairway **1701**, linear actuator **130**B rotates further forward and lower rotary actuator **138**B rotates wheel **142**B forward as wheel **142**B rests on top of step **1701**B (FIGS. **17**C and **17**D). As wheel **142**A climbs the second step **1701**B, linear actuator **130**A retracts then extends (FIGS. **17**D and **17**E). As the rearward articulated wheel assembly **120** approaches the stairway **1701**, linear actuators **130**C and **130**D split with linear actuator **130**D rotating forward (FIGS. **17**D-**17**F). As wheel **142**A reach the top of the third step **1701**C, the linear actuator **130**A extends while the linear actuator **130**D retracts and extends to place wheel **142**D on the first step **1701**A (FIGS. **17**E-**17**G). Once wheel **142**B is atop the third step **1701**C, linear actuators **130**A and **130**B align with one another (FIGS. **17**G and **17**H). As the rear articulated wheel assembly **120** climbs the stairway **1701**, linear actuators **130**C and **130**D retract and extend and lower rotary actuators **138**C and **138**D rotates wheels **142**C and **142**D as wheels **142**C and **142**D alternatingly climb each step in stairway **1701** (FIGS. **17**H-**17**L).

[**0102**] FIGS. **18**A-**18**F depict wheelchair **100** obliquely traversing a sloped surface **1801**. It should be appreciated that the movements of the articulated wheel assemblies **120** while obliquely traversing sloped surface **1801** may be somewhat similar to the movements of articulated wheel assemblies **120** when traversing slope **1401** at a perpendicular angle as depicted in FIGS. **14**A-**14**F. As wheelchair **100** begins traversing sloped surface **1801**, linear actuator **130**F rotates forward and lower rotary actuator **138**F rotates wheel **142**F forward as wheel **142**F begins to climb sloped surface **1801** (FIGS. **18**A-**18**B). As wheel **142**E begins to climb sloped surface **1801**, linear actuator **130**E rotates forward and lower rotary actuator **138**E rotates wheel **142**E forward (FIGS. **18**A-**18**C). As wheelchair **100** obliquely traverses sloped surface **1801**, the articulated wheel assemblies operate to maintain seat **105** level. As wheels **142**E and **142**F climb sloped surface **1801**, lower rotary actuators **138**A, **138**B, **138**C, **138**D, **138**G and **138**H rotate their respective wheels **142** forward. Additionally, linear actuators **130**A, **130**B, **130**C, **130**D, **130**G and **130**H extend as wheels **142**E and **142**F climb sloped surface **1801**. The combination of rotating the wheels **142** and extending the linear actuators **130** that are below the uppermost wheels combines to maintain seat **105** level (FIGS. **18**B-**18**E). As wheelchair **100** turns to begin motion away from sloped surface **1801** (FIGS. **18**C-**18**E), each of the articulated wheel assemblies **120** adjust to maintain seat **105** level and to simultaneously turn wheelchair **100**. As wheelchair **100** moves off of sloped surface **1801**, linear actuators **130**E and **130**F align (FIGS. **18**E-**18**F).

[**0103**] Although FIGS. **11**-**17** depict wheelchair **100** traversing obstacles at approximately perpendicular angles, it should be appreciated that embodiments of wheelchair **100** are capable of traversing similar obstacles at an oblique angle.

Wheel Assembly Configurations

[**0104**] The following section depicts example configurations in which the articulated wheel assemblies **120** may be placed. Other motion platforms, whether designed for wheelchairs or other uses, have fixed wheel systems that have limited or no capability to be reconfigured, either statically or dynamically. As a result, their motion patterns and steering strategies are constrained by the physical layout of their mechanical components.

[**0105**] In contrast, the articulated wheel assembly **120** of the present invention can be dynamically altered when in motion or at rest and can be used to achieve a variety of motion patterns. For example, by manipulating the angular position and lengths of the linear actuator **130**, the rotational axis of the wheels **142** can be placed at various distances from the vertical wheel assembly pivot axis **146**. This capability allows the articulated wheel assembly **120** components to be reconfigured in response to a variety of motion requirements. Example articulated wheel assembly **120** configurations include: "Omnidirectional Wheel Assembly Configuration," where the rotational axis of the wheel pairs are offset from the vertical wheel assembly pivot axis **146**; "Virtual Omnidirectional Wheel Assembly Configuration," where the rotational axis of the wheel pairs are aligned with the vertical wheel assembly pivot axis **146**; "Rough Terrain Wheel Assembly Configuration," where the individual wheels **142** of a wheel pair no longer share a common rotational axis and are offset forward or aft of the vertical wheel assembly pivot axis **146**, and "Differential Drive Wheel Assembly Configuration," where the rotational axes of the wheel pairs may be offset in any direction and at any distance from the vertical wheel assembly pivot axis **146**.

[**0106**] The ability to assume multiple articulated wheel assembly configurations **120** allows embodiments of the current invention to negotiate multiple terrain, obstacles and motion problems using the articulated wheel assembly **120** configuration and motion pattern that provides the best solution for each unique situation. Embodiments of the present invention are able to dynamically change configurations during operation. Omnidirectional Wheel Assembly Configuration.

[**0107**] Omnidirectional motion is the ability to change the direction of motion of a vehicle from a first or original direction of motion (which includes being stationary, or a "null" direction) to any second or new direction of motion without requiring transition or realignment of the motion base or the articulated wheel assemblies **120** prior to the vehicle initiating movement in the new direction of motion. As an example, a vehicle not capable of omnidirectional motion, such as a passenger automobile, must spatially travel along a circular arc as it changes from an original direction of motion to a new direction of motion. In contrast, an omnidirectional vehicle can "square the corner" as it changes from an original direction of motion to a new direction of motion without following a transitional arc. When initiating movement from a stationary position, or "null' direction of motion, reorientation of the articulated wheel assemblies **120** is not required by the omnidirectional vehicle irrespective of initial wheel **142** orientation, and vehicular motion begins in the new direction when wheel **142** rotation begins.

[**0108**] Depicted in FIG. **19** is an embodiment of the present invention with the articulated wheel assembly **120** in an omnidirectional articulated wheel assembly configuration. Omnidirectional motion can be achieved by offsetting the rotational axes of the wheel pairs from their respective vertical wheel assembly pivot axis **146** and controlling the velocities of each wheel **142** independently. The angular and translational orientation of the actuator assembly components are manipulated to align the rotational axes of the wheel **142** components of an articulated wheel assembly **120** along a common axis **1901**, which is displaced a specified offset distance **1903** either forward (as depicted in FIG. **19**) or aft of the wheel assembly vertical pivot axis **146**. When at least two articulated wheel assemblies **120** are so configured, the motion platform may be propelled in an omnidirectional manner through the vertical wheel assembly pivots **125** by applying forces to surface **156** through wheels **142**. The specified offset distance **1903** between common axis **1901** and the vertical wheel assembly pivot axis **146** may be dynamically adjusted during use to maximize performance.

[0109] As the individual wheels **142** rotate forward and/or backward, the vehicle is propelled in the new direction of motion, without requiring transition or realignment of the motion base **110** or the articulated wheel assemblies **120**. Manipulation of the rotary actuators (**135** and/or **138**) and/or the linear actuators **130** can increase or decrease the offset distance **1903** to achieve optimum velocity and/or minimum wheel slip as dictated by localized conditions.

[0110] As depicted in FIG. **20**, the wheels **142** are not initially aligned with the direction of motion **1905** (alignment A). As the wheels **142** begin to move, the applied forces result in vertical wheel assembly pivot **125** moving immediately in direction of motion **1905**. As depicted in orientations B and C, the wheels **142** rotate clockwise as vertical wheel assembly pivot **125** continues to travel in a straight line along direction of motion **1905**.

[0111] The wheels **142** attain a condition of alignment with respect to the direction of motion **1905** while propelling the vehicle in its new direction. Once the wheel pair is fully aligned, the omnidirectional characteristics of the articulated wheel assembly **120** configuration are no longer required and the articulated wheel assemblies **120** may reconfigure into another articulated wheel assembly **120** configuration, for example, the Virtual Omnidirectional Wheel Assembly Configuration, for more efficient propulsion when traveling along relatively straight paths. For illustrative purposes, the orientation of wheel assembly support strut **122** is not depicted in orientation D.

[0112] In one embodiment of the present invention, the motion platform is configured in an Omnidirectional Wheel Assembly Configuration when motionless or at slow speeds, then transitions to a Virtual Omnidirectional Wheel Assembly Configuration (described below) when at moderate to high speeds.

Virtual-Omnidirectional Wheel Assembly Configuration

[0113] FIG. **21** depicts an embodiment with the articulated wheel assembly **120** in a Virtual Omnidirectional Wheel Assembly Configuration, with common axis **1901** aligned with vertical wheel assembly pivot axis **146**. In this configuration, the propulsion motors **140** steer the wheelchair **100** by applying torque to the individual wheels **142** and causing the articulated wheel assemblies **120** to rotate around vertical wheel assembly pivot axis **146**. The wheel pairs continually rotate during steering maneuvers and wheel scrub is substantially reduced, increasing system efficiency. In the Virtual Omnidirectional Wheel Assembly Configuration, the articulated wheel assemblies **120** may be steered individually or in unison, and the vertical wheel assembly pivots **146** can be free to rotate or remain fixed to achieve a variety of steering strategies.

[0114] Depicted in FIG. **22** is an illustration showing an example movement of the wheels **142** in a virtual ominidirectional wheel assembly configuration. Initially wheels **142** are aligned in orientation A.

[0115] In contrast to the Omnidirectional Wheel Assembly Configuration, the wheel pair in Virtual Omnidirectional Wheel Assembly Configuration pivots around axis **1901** (FIG. **21**) and reorients itself to the direction of motion **2201** before movement is initiated (orientations B and C). By varying the relative velocities of the individual wheels **142** with the propulsion motors **140**, the articulated wheel assemblies **120** rotate around the vertical wheel assembly pivot axis **146** with little or no appreciable scrubbing as they orient themselves to the direction of motion **2201**. The wheels **142** then propel vertical wheel assembly pivot **125** along direction **2201** (orientation D). As wheel re-orientation occurs prior to initiation of movement in the new travel direction, the action is not considered omnidirectional. For illustrative purposes, the orientation of wheel assembly support strut **22** is not depicted in orientation D.

[0116] Although the vehicle will not immediately initiate motion if the articulated wheels **142** are misaligned with the desired direction of travel **2201**, the motion patterns will resemble those achieved in Omnidirectional Wheel Assembly Configuration when traveling at typical operating velocities. Discernable differences in relative motion patterns will tend to decrease as the vehicle accelerates from a static condition.

Rough Terrain Wheel Assembly Configuration

[0117] When aligned in a Rough Terrain Wheel Assembly Configuration, as depicted in FIG. **23**, the wheels **142**A and **142**B in each wheel pair no longer share a common axis **1901** and are each offset a distance **2303**A and **2303**B, respectively, from vertical wheel assembly pivot **146**. In the illustrated embodiment distances **2303**A and **2303**B are equal, although in alternate embodiments they are not equal. In still other embodiments, wheel axes **2301**A and **2301**B are positioned on the same side (either fore or aft) of vertical wheel assembly pivot axis **146**. The longitudinal distribution of the wheel contact area with respect to the ground plane resembles that of a larger wheel diameter, allowing the vehicle to travel over irregular terrain less accessible to motion platforms with relatively small diameter wheels. The offset distances **2303**A and **2303**B can be increased or decreased by manipulating the articulated wheel assembly actuators resulting in greater or lesser equivalent wheel diameter **2305** as needed.

[0118] Depicted in FIG. **24** is a representation depicting the motion of wheels **142** as vertical wheel assembly pivot **125** follows a curved direction of motion **2401**. Since the wheels **142** are offset fore and aft of vertical wheel assembly pivot **125**, scrubbing of the wheels occurs as vertical wheel assembly pivot **125** moves along curved path **2401**. The force imparted to the wheels **142**, as represented by arrows **2403**, are in a direction that resists the turning of the wheel assembly.

[0119] Each articulated wheel assembly **120** acts as an independently steered drive unit, both propelling and steering the vehicle as the articulated wheel assemblies **120** rotate around their respective vertical wheel assembly pivots **125** through the forces applied at the wheels **142**. Although in some embodiment this strategy superimposes a twisting moment on the individual wheels **142** by virtue of the offset distance between each wheel's contact area and its rotational axis **152**, the motion platform maintains the overall characteristics of a vehicle utilizing independent, all wheel steering.

[0120] In embodiments where all vertical wheel assembly pivots **125** are locked in a unified angular orientation to prohibit rotational motion between the articulated wheel assemblies **120** and their respective wheel assembly support struts **122**, forces can be applied to the wheels **142** to produce a controlled skidding motion, or skid steering. Although this configuration would not be appropriate for surfaces with high coefficients of friction, on loose terrain or terrain with low coefficients of friction, which are generally incompatible with traditional motion platforms, this configuration offers an enhanced method of travel that can provide both stability and high maneuverability.

Differential Wheel Assembly Configuration

[0121] In a Differential Wheel Assembly Configuration as depicted in FIG. **25**, motion patterns similar to those produced by many fixed-wheel vehicles can be reproduced, including front and rear wheel drive assistive devices where locomotive force is applied through laterally opposed drive components and steering motion is achieved through the application of a unique torque at each drive wheel.

[0122] In the depicted configuration, two adjacent vertical wheel assembly pivots **125** (see FIGS. **1-3**) remain fixed or locked, such as by engaging or disengaging a clutch mechanism, and the remaining vertical wheel assembly pivots **125** remain free to rotate about their axes. In the depicted embodiment (an example of a front wheel drive wheelchair), the front vertical wheel assembly pivots **125'** are fixed and the rear vertical wheel assembly pivots **125"** are not fixed. The wheel axes of the rotatably fixed wheel assemblies are situated a common distance **2501** from vertical wheel assembly pivot axis **146'** allowing them to act as fixed-drive wheels. In an alternate embodiment, the wheel axes **152** of the statically mounted articulated wheel assemblies **120** are aligned with the vertical wheel assembly pivot axis **146'**. The wheel axes of the remaining two articulated wheel assemblies **120** are rotatably mounted (not fixed) and are situated a common distance **2503** from the vertical wheel assembly pivot axis **146"** and are not aligned with the vertical wheel assembly pivot axis **146"**, allowing them to act as passive offset casters, and providing neither locomotive nor steering force to the vehicle.

[0123] In an alternate embodiment, the "free" articulated wheel assemblies **120** are forward of the "fixed" or "drive" articulated wheel assemblies **120** (rear wheel drive). In still further embodiments, the relative location of the "free" and "drive" assemblies is reconfigurable during operation in response to terrain conditions. In the differential wheel assembly configuration, the turning radius is a function of the distance between the "drive" wheel pairs.

[0124] In one embodiment, the Differential Wheel Assembly Configuration is used as a degraded or "fall back" operational configuration to provide basic movement capabilities during mechanical or control failures.

[0125] Illustrated in FIG. **26** is a representation depicting the motion of wheels **142** as the vertical wheel assembly pivots **125** follow the curved directions of motion **2601** and **2603**. Curved direction of motion **2601** depicts the path that the outboard vertical wheel assembly **125** follows, and curved direction of motion **2603** depicts the path that the inboard vertical wheel assembly **125** follows. As the wheels progress from orientations A-C, the outboard wheels **142** (following curved path **2601**) travel farther than the inboard wheels (following curved path **2603**). Each wheel **146** is driven at a different speed to produce the steering action and to minimize wheel scrubbing.

Motion Patterns

[0126] A feature of the present invention is the ability to transform both physically and operationally to maximize its ability to meet the challenges of a changing environment. By dynamically realigning its mechanical components, as discussed in "Wheel Assembly Configurations", and simultaneously manipulating its control, drive and steering strategies, a series of motion patterns can be produced that allow embodiments of the present invention to provide an unprecedented ability to function in diverse environments that heretofore have been considered incompatible. This ability to transition from one steering or drive mode to another contrasts with many existing vehicles that utilize static drive and steering configurations designed to address the specific motion obstacles encountered in a small set of operational conditions to the general exclusion of others, and enables embodiments of the present invention to reproduce the motion capabilities of other assistive motion platforms.

[0127] A non-exhaustive list of steering and/or drive modes that embodiments of the present invention are able to operate within and transition between include "synchronous drive/steering", "parallel all wheel drive/steering", "crab steering", "all wheel parallel steering", "Ackermann steering", "dual Ackermann steering", "pivot wheel drive", "differential drive/steering", "two wheel drive/steering", "four wheel drive/steering", "front wheel drive/steering", "rear wheel drive/steering", "mid wheel drive", "all wheel independent drive/steering", "tricycle steering""omnidirectional drive/steering", "skid steering", and "peristaltic drive/motion".

[0128] Although these drive and/or steering modes are typically considered to be discrete, in practice many interrelationships exist that result in a confusion of both terminology and function. As an example, the terms "differential drive" and "differential steering" are alternately used to describe the distinctive motion patterns generated when a vehicle is steered by applying unique and arbitrary torques to a pair of statically mounted drive wheels. In another case, those same terms are used to refer to a completely separate set of motion patterns exhibited when a vehicle with similar statically mounted drive wheels is steered by a second set of rotatably mounted wheels. For the sake of clarity in describing the features of the various embodiments of the present invention, the term "Motion Pattern" shall be used to describe a sequence of wheel and platform movements, or kinematic motion, produced through the implementation of a unified motion strategy. An example is the "Omnidirectional Motion Pattern" where changes in direction occur abruptly with no transitional radii connecting the first direction of motion to the second direction.

[0129] In turn, the term "Motion Strategy" is used to describe the unique combination of elements including drive modes, articulated wheel assembly **120** configurations, steering strategies, control logic, terrain characteristics, user preferences, etc. that produce a specific Motion Pattern in a specific environment under a specific set of circumstances. Motion Strategies may constantly transform in response to changing requirements and circumstances, and a unique Motion Pattern may be produced by any number of Motion Strategies. Microprocessor **104** receives inputs from various components of wheelchair **100** and processes these inputs to derive a motion strategy and produce the requisite outputs which are communicated to components of wheelchair **100**. Example inputs include existing wheel position, desired velocity, battery condition, sensor data, steering position, and articulated wheel assembly configuration. Example outputs include commanded motor torques and actuator angles.

[**0130**] While the ability to transition from one Motion Strategy to another by reconfiguring physical and operational parameters allows a unique level of versatility, the further ability of embodiments of the present invention to do so dynamically as the vehicle travels through diverse settings, allows it to overcome the boundaries between machine and environment that heretofore have prevented users of assistive motion platforms from moving about their surroundings in an intuitive manner.

[**0131**] As an example of intuitive motion as provided by embodiments of the present invention, an omnidirectional motion pattern may be selected to maneuver where the need for instantaneous, low speed lateral motion is paramount, for example, in a constricted office environment. As the user moves to the out of doors, where greater distances must be traveled over paved surfaces, the vehicle reconfigures itself into a more energy efficient virtual-omnidirectional movement strategy that provides the functional advantages of omnidirectional motion patterns at higher speeds. When the need arises to travel over irregular natural terrain, the vehicle reconfigures its articulated wheel assemblies **120** for maximum traction and stability, while maintaining the maneuverability obtained with virtual omnidirectional motion patterns. Finally, when the user is confronted with an abrupt change in elevation, the vehicle transitions into climbing mode, where it utilizes the capabilities of the articulated wheel assemblies **120** to scale the obstacle without outside assistance.

[**0132**] FIGS. **27-30** depict a limited set of motion patterns produced by embodiments of the present invention. Although the depicted motion patterns are representative of those required to execute many motion strategies, other motion patterns may be used as required.

Omnidirectional Motion Pattern

[**0133**] FIG. **27** depicts the sequenced movement through orientations A-F of wheelchair **100** along path **2705** according to one embodiment of the present invention using an omnidirectional motion pattern as wheelchair **100** negotiates the tight spaces between desk **2701** and wall **2703** of a simulated office floor plan. At the beginning of the sequence (orientation A), wheelchair **100** is adjacent desk **2701** with the user (not depicted) seated at desk **2701**. In orientation A, the articulated wheel assemblies **120** are not aligned with the desired path **2705**. With the articulated wheel assemblies **120** in the omnidirectional configuration, the wheelchair **100** immediately begins movement along path **2705** as the wheels **142** begin rotating. As wheelchair **100** travels, the articulated wheel assemblies **120** align with the direction of travel (orientations A-D). Despite being initially misaligned with the new direction of motion as wheelchair **100** travels around the corner of desk **2701** (orientation D), wheelchair **100** is able to "square" the corner without pausing to realign the articulated wheel assemblies **120**, which remain in the omnidirectional configuration. After wheelchair **100** negotiates the corner of desk **2701**, the articulated wheel assemblies **120** again align with the new direction of motion (orientations D-F). When initiating or changing direction, movement in the new direction is immediate and the path is direct. This ability to move in any direction closely mimics intuitive motion patterns that have previously been difficult, if not impossible, for users with typical wheelchairs to achieve. Although used to illustrate the omnidirectional motion pattern, it should be appreciated that the omnidirectional configuration may be used with other motion patterns.

Synchronous Steering Motion Pattern

[**0134**] Driving and steering all four articulated wheel assemblies **120** in a similar fashion as though they were mechanically linked to each other produces the synchronous steering motion pattern as depicted in FIG. **28**. In the illustrated example, the articulated wheel assemblies **120** are arranged in a virtual-omnidirectional wheel assembly configuration, although a synchronous steering motion pattern may be produced with other wheel assembly configurations. In orientation A, the user (not depicted) is seated at desk **2701** and the wheels **142** of articulated wheel assemblies **120** are not aligned with the desired path **2805**. As such, when motion is commanded by the user, the wheel assemblies **120** rotate in unison to align wheels **142** with the desired path **2805** prior to initiation of motion along path **2805**. As wheelchair **100** moves along path **2805**, the wheels **142** remain aligned with the direction of motion and with one another (orientations B and C).

[**0135**] As wheelchair **100** negotiates around the corner of desk **2701**, the wheelchair **100**"rounds" the corner to maintain forward velocity of wheelchair **100**. Additionally, as wheelchair **100** turns, the motion base **110** can rotate independently from the seat **105** and does not necessarily maintain a front/back orientation in relation to the direction of motion. It should be appreciated that wheelchair **100** is capable of "squaring" the corner, although wheelchair **100** would be required to stop and allow the articulated wheel assemblies **120** to reorient to the new direction of motion in order to "square" the corner. As wheelchair **100** continues along desired path **2805** (orientations E and F), wheels **142** are aligned with the direction of motion. In the illustrated embodiment, wheel scrubbing will occur with the wheels **142** aligning themselves with a new direction of travel before motion is initiated, especially with embodiments utilizing single wheel articulated assemblies. In the depicted sequence, the seat **105** does not change its orientation as the wheelchair **100** turns. This feature can be desirable, although in other situations it may be desirable to separately rotate seat **105** to coordinate with the directional movement. Independent All Wheel Steering Motion Pattern

[**0136**] As depicted in FIG. **29**, the articulated wheel assemblies **120** are driven and steered independently to produce the independent all wheel steering motion pattern. While maneuvering with the independent all wheel steering motion pattern, the wheel rotation axes **152** intersect at the instantaneous center of rotation **2907** (depicted in orientation D) and wheel scrub is effectively eliminated. When traveling in a straight line, the wheel rotation axes **152** are parallel, the turn radius is infinite, and the instantaneous center of rotation is an infinite distance from the platform (orientations E and F). When pivoting in one location, the turn radius is zero and the instantaneous center of rotation is beneath the platform. As such, the turn radius can vary from infinity to zero, giving the wheelchair **100** a full range of maneuverability with little or no scrubbing inefficiencies.

[0137] In the illustrated sequence of FIG. **29**, the articulated wheel assemblies **120** are in the virtual-omnidirectional configuration and a steering strategy is chosen to produce an independent all wheel steering motion pattern. In the depicted sequence, as the wheelchair **100** moves between orientations A and B, the seat **105** rotates to align with the direction of motion along path **2905**. In contrast to the sequences depicted in FIGS. **27** and **28**, as wheelchair **100** negotiates around the corner of desk **2701**, the motion base **110** rotates as the wheelchair **100** turns. Although the wheelchair **100** is depicted as following a curved path **2905** between orientations A and E, it should be appreciated that wheelchair **100** is capable of "squaring" the corner of desk **2701** using an independent all wheel steering motion pattern with wheelchair **100** pivoting as it travels around the corner of desk **2701**.

[0138] As each wheel pair is steered and driven independently to produce an independent all wheel steering motion pattern, this motion pattern can mimic the motion patterns produced by various other steering strategies, for example, "all wheel parallel" steering, "Ackermann" steering, "dual Ackermann" steering, "pivot wheel" steering, "differential" steering, and "tricycle" steering. In one embodiment of the present invention, the wheelchair travels in an independent all wheel steering motion pattern when traveling at speeds approximately equal to average walking speeds or faster.

Differential Steering Motion Pattern

[0139] FIG. **30** depicts a wheelchair **100** maneuvering in a differential steering motion pattern (represented by orientations A-H). The illustrated sequence is required for a typical powered differential drive wheelchair or a manual wheelchair with fixed drive wheels when traveling around an obstacle in a confined space. In the illustrated embodiment, articulated wheel assemblies **120** are arranged in a differential wheel assembly configuration with the rear articulated wheel assemblies **120**"locked" and the forward articulated wheel assemblies unpowered and allowed to caster. To move the user (not depicted) from the seated position at table **2701**, wheelchair **100** initially moves backward (orientations A and B). As wheelchair **100** begins to move forward (orientations B and C), the articulated wheel assemblies **120**, acting as passive casters, begin to orient with the direction of travel along path **3005**. In the illustrated example, wheelchair **100** cannot maneuver around the corner of table **2701** while maintaining a forward velocity, and wheelchair **100** is required to "back up" and perform a "multi-point turn" in order to maneuver around the corner of table **2701** (orientations E and F). Unlike the motion patterns depicted in FIGS. **27** and **28**, the motion base **110** rotates as wheelchair **100** maneuvers around table **2701**. As wheelchair **100** continues along path **3005**, articulated wheel assemblies **120**, acting as passive casters, align with the direction of motion (orientations G and H). The "locked" articulated wheel assemblies **120**, which include the drive wheels, are aligned with the direction of motion along path **3005**. The relatively wide turning radius associated with a differential steering motion pattern makes this type of motion particularly unwieldy in confined spaces. In an embodiment of the present invention, a differential steering motion pattern is used as a degraded mode of operation, which may be used when components of wheelchair **100** malfunction.

[0140] While the illustrations have depicted articulated wheel assemblies **120** with two hubless wheels **142**, two propulsion motors **140**, two upper rotary actuators **135**, two linear actuator motors **136**, and two lower rotary actuators **138**, alternate embodiments include other combinations and/or configurations. Examples of such alternate embodiments, combinations and configurations are included below. For example, some embodiments include two propulsion motors **140** and two rotary wheel actuators attached to a single linear actuator **130**. Still other embodiments utilize articulated wheel assemblies **120** with a single upper rotary actuator **135**, a single linear actuator **130**, a single lower rotary actuator **138**, a single propulsion motor **140** and a single hubless wheel **142**. Additionally, the depicted propulsion motors **140** and lower rotary actuators **138** may be physically separated devices, or may be combined into a single device.

[0141] Other embodiments of the present invention utilize front wheel drive, where only the front wheels are powered and the rear wheels act as passive casters, while still other embodiments utilize rear wheel drive, where only the rear wheels are powered and the front wheels act as passive casters.

[0142] Another feature of an embodiment of the present invention is derived from the ability to vary the horizontal distance between the vertical wheel assembly pivot axis **146** and the rotational axis **152** of the wheels **142**. The ratio between this horizontal distance and the distance between the two wheels on each articulated wheel assembly **120** influences the overall size of the articulated wheel assembly **120** and the amount of wheel slippage that can occur during operation. Too small of a ratio can result in actuator saturation, and too large of a ratio can result in a large articulated wheel assembly **120** with associated clearance problems. The ability to vary the horizontal distance between the vertical wheel assembly pivot **146** and the propulsion motor **140** during operation provides the ability to achieve optimal performance in multiple situations.

[0143] Yet another feature present in embodiments of the present invention is derived from the placement of a linear actuator **130** between the offset connecting arm **128** and the wheel. The use of the linear actuator **130** in this fashion results in the linear actuator **130** acting as a "reverse offset link." This "double link" arrangement of the offset connecting arm **128** and the linear actuator **130** allows for dynamic adjustment of the platform height and wheelbase when combined with the upper rotary actuator. Angular adjustments in response to terrain obstacles and active suspension capabilities, while maintaining enhanced omnidirectional capabilities.

[0144] Further features of other embodiments of the present invention derive from the use of hub mounted motors. The hub mounted motors enable the lowering of the center of gravity, help distribute component weight evenly around the platform, use otherwise unused space, increase mounting opportunities, and act as attachment points for other articulated wheel assembly **120** components.

[0145] Another feature of another embodiment of the present invention is the ability to use wheels with diameters larger than those of other types of motorized multi-directional vehicles, for example ball wheels or Killough wheels. The larger diameter wheels allow for operation on rough terrain, soft surfaces and stabilize climbing operations.

[0146] Still a further feature of other embodiments of the present invention is derived from the eccentrically mounted wheel motors and rotary wheel actuators. This configuration provides the ability to rotate the wheel about the wheel's center and/or the rotary actuator's center. This combination of motions allows for a combination of articulated wheel assembly **120** extension and rotational stepping action without inhibiting forward motion when small obstacles are encountered.

[0147] Still another feature realized by other embodiments of the present invention derives from the ability of the articulated wheel assemblies **120** to achieve multiple drive configurations and operate in multiple steering modes over a wide range of terrains and operating conditions. The articulated wheel assemblies **120** are capable of making dynamic adjustments to their configuration to provide an efficient and effective drive strategy.

[0148] In an alternate embodiment of the present invention, which may be referred to as "double wheels, rigid link," each articulated wheel assembly **120** includes a pair of drive assemblies rotatably and eccentrically mounted to a single rigid link which may be pivotably or rigidly coupled to the free end of an offset wheel assembly connecting arm **128** along a common transversal axis or attachment point, which in turn is rotatably coupled to the motion base **110** through a vertical wheel assembly pivot **125**.

[0149] In an alternate embodiment of the present invention, which may be referred to as "double wheels, single actuator," each articulated wheel assembly **120** includes a pair of drive assemblies rotatably and eccentrically mounted to a single linear actuator **130** which may be pivotably or rigidly coupled to the free end of an offset wheel assembly connecting arm **128** along a common transversal axis or attachment point, which in turn is rotatably coupled to a motion base **110** through a vertical wheel assembly pivot **125**.

[0150] In an alternate embodiment of the present invention, which may be referred to as "single wheel, single actuator," each articulated wheel assembly **120** includes a single drive assembly rotatably and eccentrically mounted to a single linear actuator **130** which is either pivotably or rigidly coupled to the free end of an offset connecting arm **128** along a common transversal axis or attachment point.

[0151] In an alternate embodiment of the present invention, which may be referred to as "alternate payload," a vehicle, or motion platform with articulated wheel assemblies **120** is provided for transporting a non-human payload over a multiplicity of terrain and obstacle configurations. The embodiment may include a payload platform for supporting a payload and a motion base **110** statically or rotatably coupled to the payload platform, or the payload platform may be an integral member of the motion base **110**. Alternately, the payload platform and the motion base **110** may be separate entities that are not part of an integrated motion platform assembly or are coupled in a non-congruent manner.

[0152] In an alternate embodiment of the present invention, which may be referred to as "changing track width," a motion base **110** is provided that includes two or more wheel assembly support struts **122** arranged in a radial symmetry around, and rotatably coupled to a central support hub **124**, allowing realignment of the angular pose of the support struts **122** in the horizontal plane. One or more wheel assembly support strut pivot actuators **126** may be mechanically coupled to the support struts **122**, allowing a dynamic readjustment of track width in response to changing pathway configurations.

[0153] In an alternate embodiment of the present invention, which may be referred to as "alternate payload platform," a payload platform may be movably coupled to a motion base **110**, comprised of a rigid, deformed plane of varying thickness and composition that acts to provide support for three or more articulated wheel assemblies **120** that are rotatably coupled to the motion base **110** through vertical wheel assembly pivots **125**.

[0154] In an alternate embodiment of the present invention, which may be referred to as "alternate motor types," each drive assembly includes a hubless or otherwise configured wheel, directly or remotely coupled to a hub motor, torque motor, ring motor, pancake motor, servo-disc motor, or other mechanical or electrical actuator and/or power transmission components capable of providing locomotive torque to the wheel components.

[0155] In accordance with a feature of the present invention, which may be referred to as "stepping action," the angular and translational orientation of an actuator assembly may be manipulated so as to place wheel rotational axes **152** of wheels **142** at various points along a plane longitudinally bisecting the actuator assembly, allowing the wheel components to replicate a stepping type action, alternately stepping onto or over obstacles or abrupt elevational changes in the pathway configuration.

[0156] In accordance with another feature of the present invention, which may be referred to as "level seat," the angular and translational orientation of the actuator assembly components may be manipulated in a dynamic fashion so as to increase or decrease the effective length of the individual articulated wheel assemblies **120** supporting the motion base **110** at a distance above the ground plane, thereby maintaining a level or otherwise optimal posture independent of changing path configurations.

[0157] In accordance with a preferred embodiment of the present invention, which may be referred to as "drive & steering configurations," a vehicle, or motion platform with two or more articulated wheel assemblies **120** is provided. Each articulated wheel assembly **120** includes two discrete drive assemblies, each with independently driven and articulated wheel systems. Each wheel system is coupled to a wheel mounted motor which provides both propulsion and steering force by applying unique torques to the opposing wheel pair. The propulsion motors **140** may act individually or in unison with any or all alternate drive assembly motors, providing a multiplicity of potential drive and steering configurations as required to produce a desired motion strategy. In a degraded condition, for example due to mechanical or electrical failure, various drive configurations may be utilized to provide emergency propulsion with remaining resources.

[0158] In accordance with still another feature of the present invention, which may be referred to as "pivoting wheel," a drive assembly is provided consisting of a hubless wheel system coupled to a discrete propulsion motor **140** and rotatably attached to an actuator whose rotational axis is eccentrically offset by a specified distance from the centrally located rotational axis of the wheel components. The eccentrically mounted rotary actuator may be a part of an actuator assembly acting as an articulated link between the drive assembly and the offset wheel assembly connecting arm. By applying a torque at the rotary actuator, the wheel components pivot in an eccentric fashion around the rotational axis of the actuator, allowing both a compressed and extended configuration as well as a compact stepping motion when operated in a coordinated manner with other components of the motion base **110**.

[0159] In accordance with yet another feature of embodiments of the present invention, the angular and translational orientation of the actuator assembly components may be reconfigured so as to align the rotational axes of the individual wheel components at various points along a plane longitudinally bisecting the actuator assembly, providing a multiplicity of wheel assembly configurations.

[0160] In an alternate embodiment, two bilaterally mounted articulated wheel assemblies **120** may be aligned to allow a common axis to pass through the rotational axes of their respective wheel components. The vertical wheel assembly pivots **125** may be made fixed as with a clutch mechanism so as to inhibit rotational motion between the articulated wheel assemblies **120** and the motion base **110**. The common rotational axis of the articulated wheel assemblies **120** may be placed at any arbitrary distance from a downward projection of the vertical pivot axes, allowing a torque differential applied at the opposing articulated wheel assemblies **120** to provide steering force to the vehicle by causing the motion base **110** to rotate about the midpoint of the common wheel assembly axis.

[0161] In accordance with one feature of embodiments of the present invention, the angular and translational orientation of the actuator assembly components may be manipulated in a dynamic fashion to increase or decrease the effective length of the individual articulated wheel assemblies **120** and their angle with respect to the ground plane.

[0162] In one embodiment, as the length of the actuator assembly is increased or decreased and its angle with regard to the ground plane is decreased or increased, respectively. As such, the articulated wheel assemblies **120** are manipulated to extend or contract the wheelbase of the vehicle without altering the distance between the payload platform and the ground plane, thus providing increased stability with the actuators extended and decreased vehicle length with the actuators retracted.

[0163] In an alternate embodiment, as the length of the actuator assembly is increased or decreased, its angle with regard to the ground plane is increased or decreased, respectively. As such, the articulated wheel assemblies **120** can be manipulated to increase or decrease height payload without altering the platform wheelbase, providing enhanced high reach and low reach capabilities.

[0164] In accordance with further features of the present invention, the angular and translational orientation of the actuator assembly components may be manipulated to increase or decrease the effective length of the individual articulated wheel assemblies **120** and their angle with respect to the ground plane, resulting in a lengthening or shortening of the vehicle wheelbase. Additionally, the angular orientation of the wheel assembly support struts **122** may be manipulated to increase or decrease the lateral distance between pairs of articulated wheel assemblies **120**, resulting in a narrowing or widening of the vehicle track width. Both track width and wheel base can be increased when increased stability is required such as during high speed travel. Alternatively, both track width and wheel base can be decreased when increased maneuverability is required, such as during movement in confined spaces.

[0165] Some embodiments are limited to fewer features than the total number of features disclosed. These limited feature models may be useful to provide some reduced functionality for entry level models or models that are more tailored to a specific task for specialty use. For example, while embodiments depicted in the illustrations include a pivotal attachment between the extension arm and the seat support structure, other embodiments include extension arms rigidly attached to the seat support structure.

[0166] While example embodiments of the invention have been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only exemplary embodiments have been shown and described and that all changes and modifications that come within the spirit of the invention are desired to be protected. Dimensions, whether used explicitly or implicitly, are not intended to be limiting and may be altered as would be understood by one of ordinary skill in the art.

What is claimed is:

1. A vehicle, comprising:

a payload platform;

an offset link with a proximal end and a distal end, said offset link proximal end pivotally connected with a vertically aligned pivot axis to said payload platform, and said offset link distal end positioned a horizontal distance from said vertically aligned pivot axis;

a first extendable member with a proximal end, a distal end, a first length and a first extension motor, said first extendable member proximal end pivotally connected to said offset link distal end, wherein said first extension motor changes said first length, and wherein said first length and said vertically aligned pivot axis define a first swing angle;

a first rotating motor connected to said first extendable member and said offset link, wherein said first rotating motor rotates said first extendable member and changes said first swing angle;

a first wheel with a first central axis, said first wheel rotatably connected to said first extendable member distal end; and

a first drive motor coupled to said first wheel, wherein said first drive motor rotates said first wheel around said first wheel central axis.

2. The vehicle of claim 1, further comprising:

a second extendable member with a proximal end, a distal end, a second length and a second extension motor, said second extendable member proximal end pivotally connected to said offset link distal end, wherein said second extension motor changes said second length, and wherein said second length and said vertically aligned pivot axis define a second swing angle;

a second rotating motor connected to said second extendable member and said offset link, wherein said second rotating motor rotates said second extendable member and changes said second swing angle;

a second wheel with a second central axis, said second wheel rotatably connected to said second extendable member distal end; and

a second drive motor coupled to said second wheel, wherein said second drive motor rotates said second wheel around said second wheel central axis.

3. The vehicle of claim 2, wherein said first wheel and said second wheel are spaced apart six (6) inches.

4. The vehicle of claim 1, wherein said payload platform is a wheelchair and includes a seat configured to transport a person, and further includes a user control for the user to control the movement of the wheelchair.

5. The vehicle of claim 1, wherein said payload platform includes a payload support member and a support strut with a proximal end and a distal end, said support strut proximal end pivotally connected to said payload support member and said offset link pivotally connected to said support strut distal end.

6. The vehicle of claim 5, wherein said pivotal connection between the support strut proximal end and said payload support member is selectably lockable.

7. The vehicle of claim 1, further comprising a second rotating motor with a rotational axis offset a distance from said wheel central axis, said second rotating motor connected to said extendable member and said wheel, wherein said second rotating motor rotates said wheel central axis around said second rotating motor rotational axis.

8. The vehicle of claim 1, wherein said first extendable member length is at least twelve (12) inches and at most twenty-four (24) inches.

9. The vehicle of claim 1, wherein said first wheel has a diameter equal to eight (8) inches.

10. The vehicle of claim 1, wherein said offset link distal end is positioned a horizontal distance from said vertically aligned pivot axis equal to four (4) inches.

11. The vehicle of claim 1 further comprising a microprocessor for controlling said first extension motor, said first rotating motor and said first drive motor.

12. The vehicle of claim 11 further comprising a battery for providing power to said microprocessor, said first extension motor, said first rotating motor and said first drive motor.

13. A wheelchair for transporting a person across a surface, comprising:

a seat for carrying a person; and

an articulated wheel assembly, including:

an offset member with a proximal end and a distal end, said proximal end pivotally connected to said seat with a vertically aligned pivot axis, said distal end positioned a horizontal distance from said vertically aligned pivot axis;

an extendable member with a first opposing end, a second opposing end and a length, said extendable member first end connected to said offset member distal end, and said extendable member second end positioned on an opposite side of the vertical pivot axis from said offset member distal end;

an extension motor connected to said extendable member, wherein said extension motor changes said extendable member length;

a wheel connected to said extendable member second end; and

a propulsion motor connected to said wheel, wherein said propulsion motor rotates said wheel.

14. The wheelchair of claim 13 comprising four articulated wheel assemblies.

15. The wheelchair of claim 13, wherein said extendable member intersects said vertically aligned pivot axis.

16. The wheelchair of claim 15, wherein the extendable member forms an angle of fifty (50) degrees with said vertically aligned pivot axis.

17. The wheelchair of claim 13, wherein said wheel is hubless.

18. A wheelchair for transporting a person across a surface, comprising:

a seat for carrying a person; and

an articulated wheel assembly, including:

an offset member with a proximal end and a distal end, said proximal end pivotally connected to said seat with a vertically aligned pivot axis, said distal end positioned a horizontal distance from said vertically aligned pivot axis;

an elongated member with a first opposing end, a second opposing end and a central axis between said first and second opposing ends, said elongated member first end connected to said offset member distal end;

a rotating motor connected to said offset member and said elongated member, wherein said rotating motor changes the angle between said vertically aligned pivot axis and said elongated member central axis;

a wheel connected to said elongated member second end; and

a propulsion motor connected to said wheel, wherein said propulsion motor rotates said wheel.

19. The wheelchair of claim 18 comprising four articulated wheel assemblies.

20. The wheelchair of claim 18, wherein said wheel is hubless.

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